In Situ Thermal NAPL Remediation Technologies

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Outline of Presentation

In Situ Thermal Treatment

- Practical/Policy Overview
- General Principles of In Situ Thermal Treatment
- Specific Technologies and Case Studies
  - Steam Enhanced Extraction
  - Electrical Resistance Heating
  - Electrical Conductive Heating
- Summary/Conclusions
- Contacts
- Technology Vendor Information
- References

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Limitations of Extraction-Based In Situ Technologies

In Situ Thermal Treatment

- Contaminant volatility, solubility and/or desorption is limited at ambient temperatures
  - VOCs in saturated zone not amenable to SVE
- Subsurface heterogeneities/low-permeability zones hamper recoveries
  - Lack of advective flow
  - Mass transfer becomes diffusion limited (very slow)
- Contaminant recovery often declines asymptotically before remedial goals are met

Bottom Line

In Situ Thermal Treatment

- Pump-and-Treat is a Protracted Containment Remedy

- "O&M" takes on a whole new dimension for decades/centuries-long projects

Site Categories with Significant NAPL

In Situ Thermal Treatment

- Wood treaters
- Manufactured Gas Plant (MGP) sites
- Chlorinated solvent sites
- Drycleaners
- Large petroleum hydrocarbon releases (esp. below the water table)
- Fractured media

Policy Infrastructure

In Situ Thermal Treatment

- Technical Impracticability Waiver Guidance
- Monitored Natural Attenuation Policy
- ROD for Del Amo Superfund site
- ROD for Calhoun Park Superfund site
- State policies

Technical Impracticability Waiver Guidance

In Situ Thermal Treatment

- "…**Sources should be located and treated or removed where feasible** and where significant risk reduction will result, regardless of whether EPA has determined that groundwater restoration is technically impracticable…"

Directive 9234.2-25

Monitored Natural Attenuation Policy

In Situ Thermal Treatment

- "…EPA expects that MNA will be **most appropriate when used in conjunction with other remediation measures** (e.g., **source control**, groundwater extraction), or **as a follow up to active remediation measures** that have already been implemented…"

Directive 9200.4-17P

Del Amo ROD Excerpt

In Situ Thermal Treatment

- "…When NAPL is recovered from the ground, its mass and saturation are reduced. In principle, this can (1) **reduce the amount of time** that the containment zone must be maintained, (2) **reduce the potential for NAPL to move** naturally either vertically or laterally, and (3) **increase the long-term certainty** that the remedial action will be protective of human health and remain effective..."

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What’s New

In Situ Thermal Treatment

- Potential to address vadose zone semivolatile organic compound (SVOC) contamination not amenable to soil vapor extraction (SVE)

- Potential to address contamination in the saturated zone below the water table

- Ability to address contamination at depths below those amenable to excavation

Good News and Bad News...

In Situ Thermal Treatment

- Good tools but not silver bullets
  - Able to achieve MCL-type cleanup objectives in some but not all situations
  - Greatly accelerate remediation timeframes
  - May involve significant capital expenditures (but significantly reduced O&M timeframes)

General Situation

In Situ Thermal Treatment

- "Take-off" phase for simpler solvent sites in the $2M to $6M range
- Building pressure, but continued responsible party (RP) reluctance to address more costly, complex sites with large quantities of contamination

In Situ Thermal Treatment: Mechanisms

In Situ Thermal Treatment

- Volatilization
- Steam Distillation
- Boiling
- Oxidation
- Pyrolysis
- Natural Surfactant Generation (?)

"Translation" Matrix

In Situ Thermal Treatment

- **Steam Enhanced Extraction**
  - Also referred to as Dynamic Underground Stripping (DUS)
- **Electrical Resistive Heating**
  - Six-Phase Heating/Three-Phase Heating
- **Electrical Conductive Heating**
  - In Situ Thermal Desorption (ISTD)

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Components of Steam Enhanced Extraction

"Tool box" of in situ remedial technologies

- ***Steam Injection*** to heat the formation
- ***Hydrous Pyrolysis Oxidation (HPO)*** to oxidize residual contaminants
- ***Electrical Resistance Tomography (ERT)*** for measuring heat distribution (in situ process control)
- ***Joule Heating (3-Phase)*** of low permeability areas (if required)
- ***Extraction Systems*** to recover vapors and liquids
- ***Treatment Systems*** for recovered free product, vapors, liquids

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Case Study

The Visalia Steam Remediation Project

Pole Yard History

The Visalia Steam Remediation Project

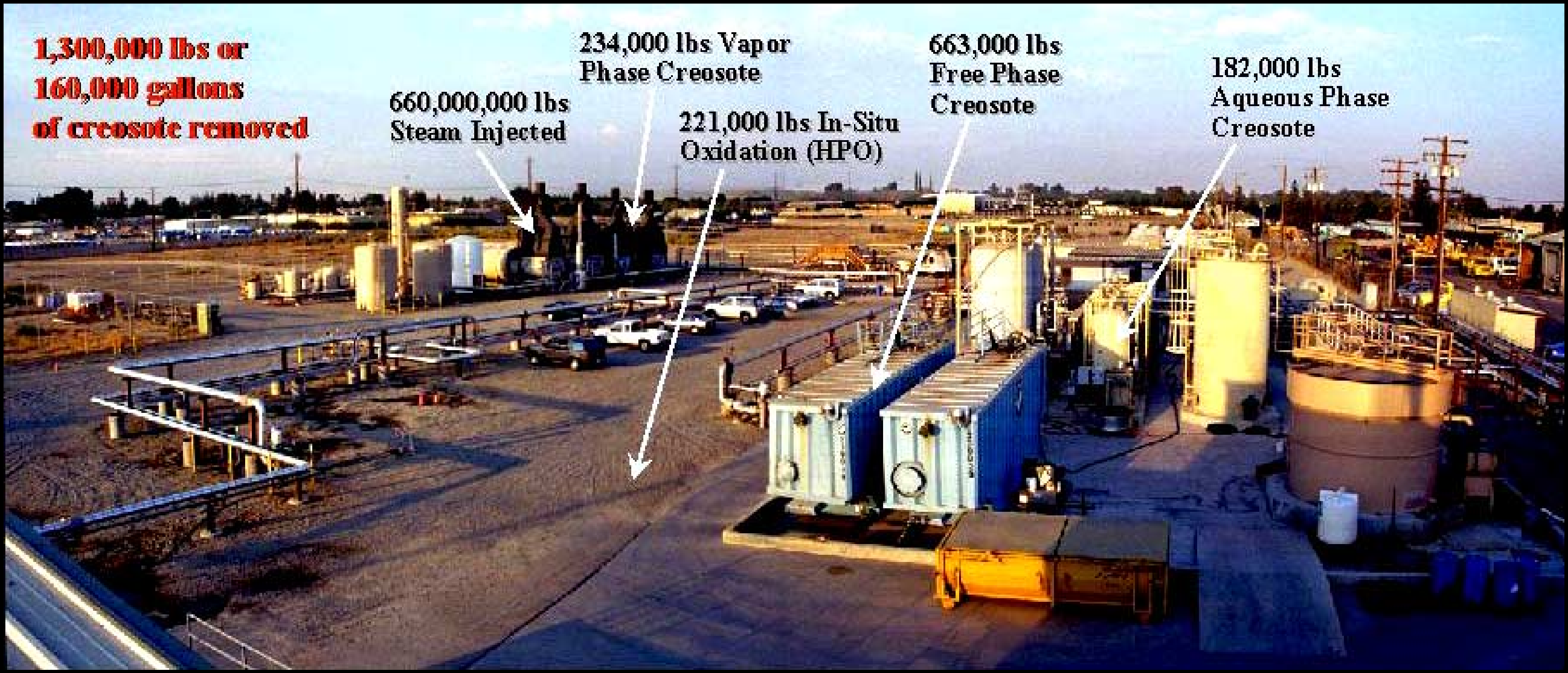
- 1923 -1980: Wood Treatment Plant operation (creosote/PCP)
- 1976: Groundwater Pumping Initiated
- 1977: Grout Wall Completed
- 1985: Phase 1 Water Treatment Plant
- 1985: Cal-EPA Superfund Site
- 1987: Phase 2 Water Treatment Plant
- 1989: U.S. EPA Superfund Site – No. 199
- 1992: RI/FS Completed
- 1994: RAP/ROD – Enhanced In Situ Bioremediation originally selected
- 1995: Regulatory approval for in situ thermal remedy
- 1996: Design and Construction
- 1997: Steam Enhanced Extraction Remedial Action

Visalia Site Layout

The Visalia Steam Remediation Project

Creosote Removed

The Visalia Steam Remediation Project



Major Visalia Achievement

The Visalia Steam Remediation Project

- Source Removal
  - Pump-and-treat produced 400 lbs of DNAPL per year
  - DUS produced 1,300,000 lbs of DNAPL in 36 months

Phase I Steam Injection

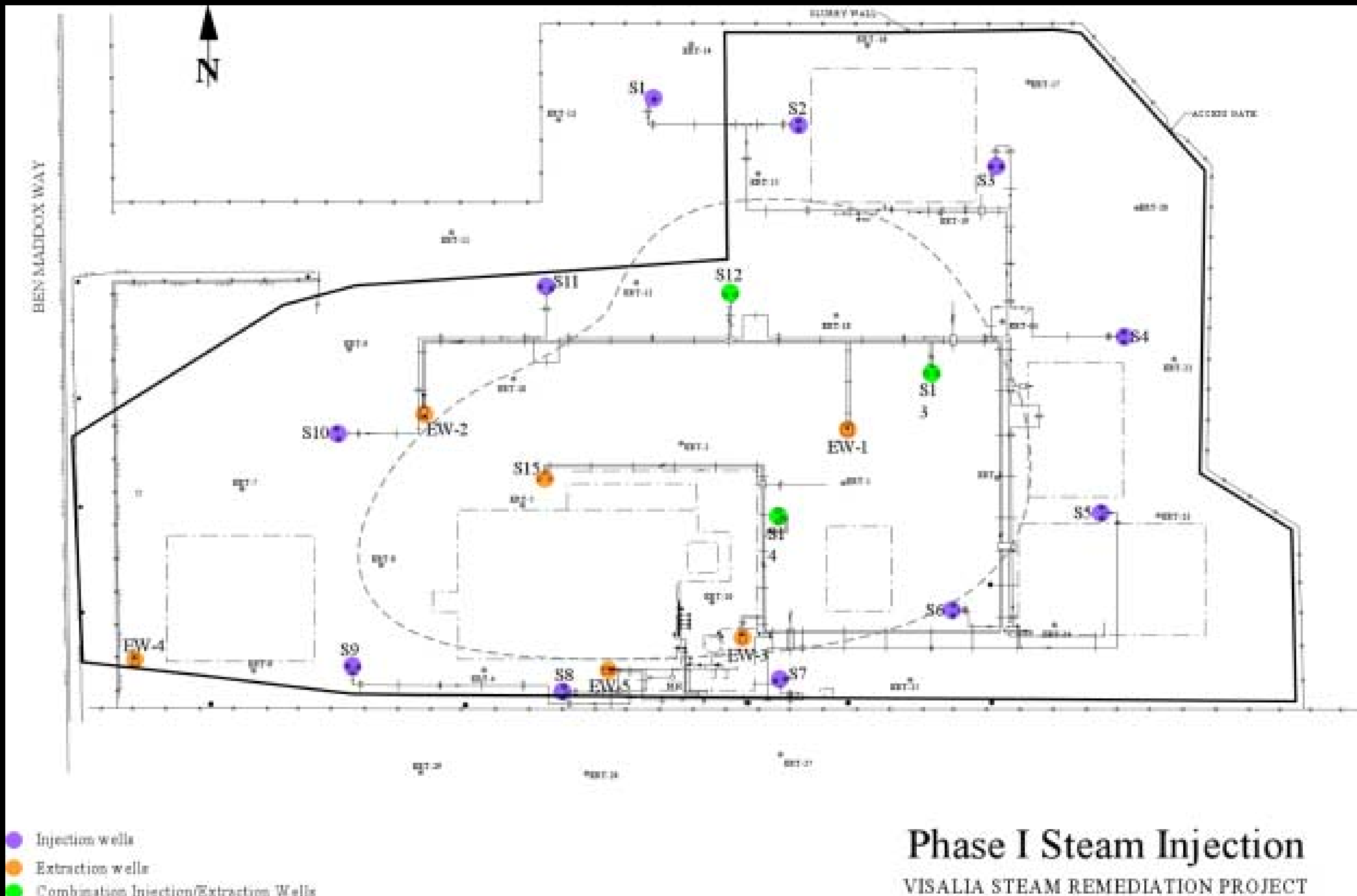
The Visalia Steam Remediation Project

- Objective:
  - Clean the groundwater to acceptable contaminant levels at a lower cost and faster schedule than pump-and-treat

- Methodology:
  - Thermally treat the intermediate aquifer and aquitard
  - Use steam flood to achieve convection and conduction heating of the target zone

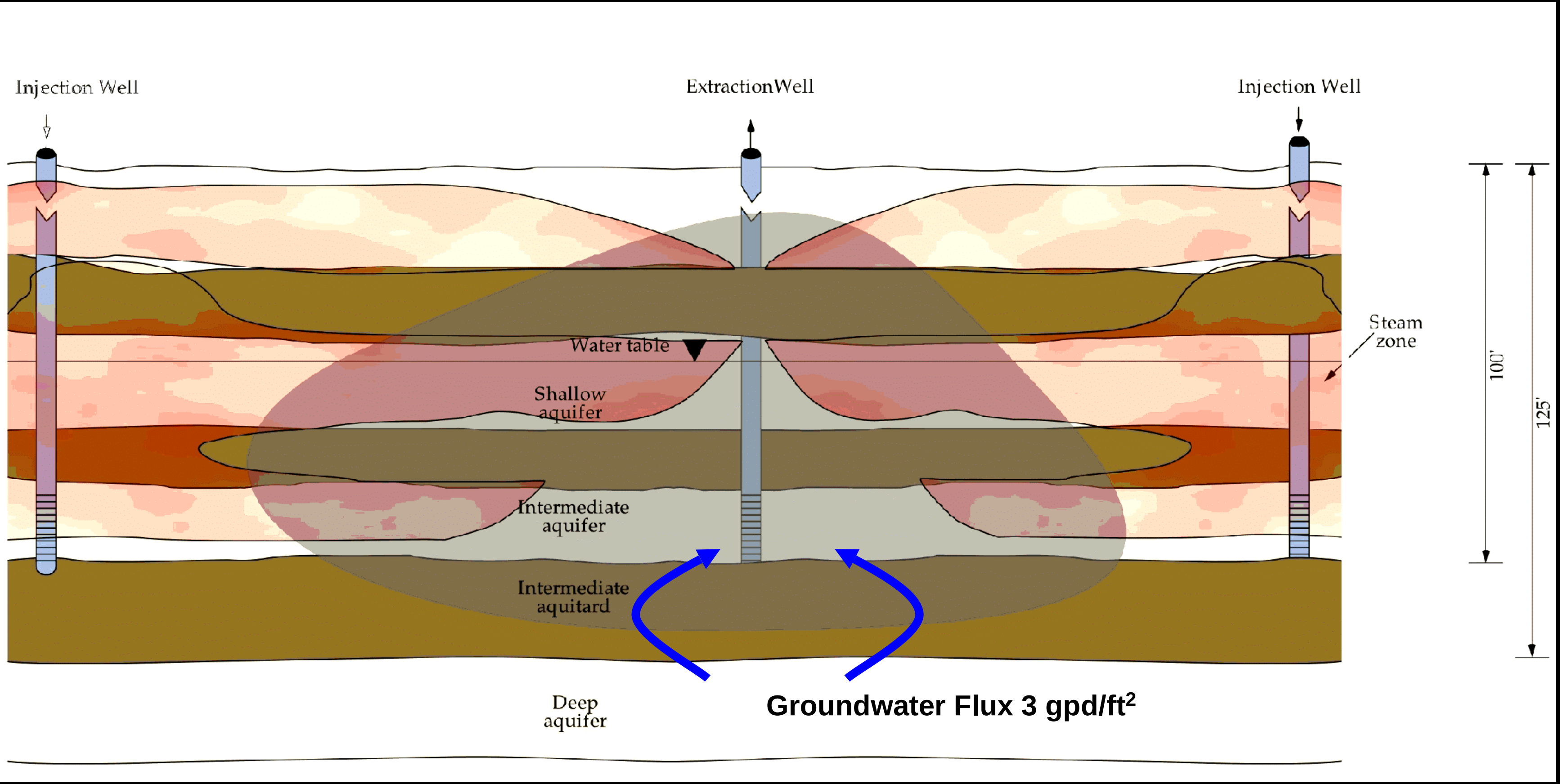
Phase I Wellfield Layout

The Visalia Steam Remediation Project



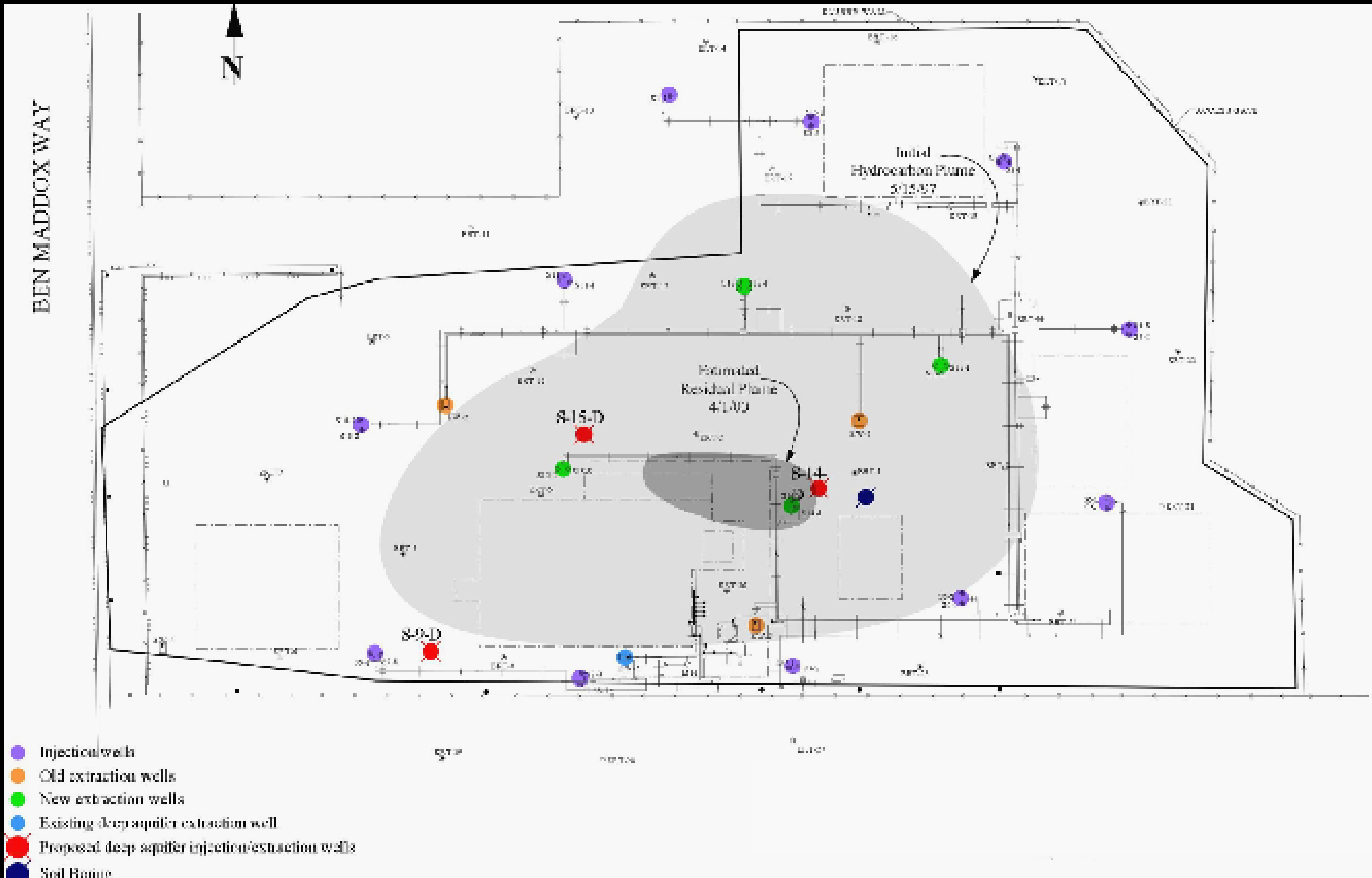
Phase I Steam Injection Cross Section

The Visalia Steam Remediation Project



Phase I Results: Creosote Plume Reduction with DUS

The Visalia Steam Remediation Project



Phase I Results

The Visalia Steam Remediation Project

- **1.78** Acres Treated
  - 20 ft to 95 ft Depth
- **890,000** Pounds of Creosote (DNAPL) Removed
- **Lessons Learned**
  - Wellfield modifications needed to evenly distribute heat
  - Classical steamflood method required modification
  - Creosote became LNAPL at temperatures > 50°C
  - Contaminant volume underestimated (model)

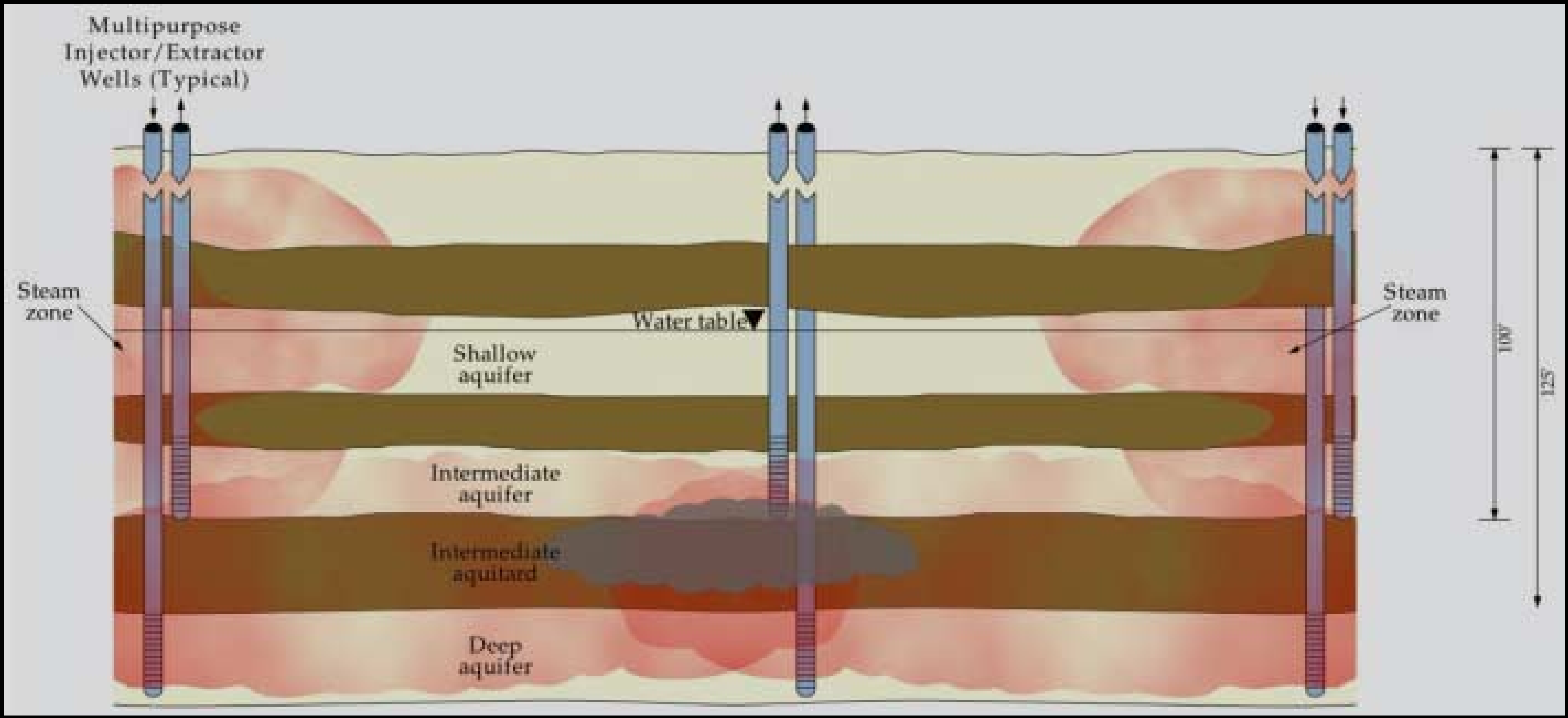
Phase II Steam Injection

The Visalia Steam Remediation Project

- Objective:
  - Thermally treat remaining DNAPL mass in the intermediate aquitard
- Methodology:
  - Use innovative steam management: vertical steaming

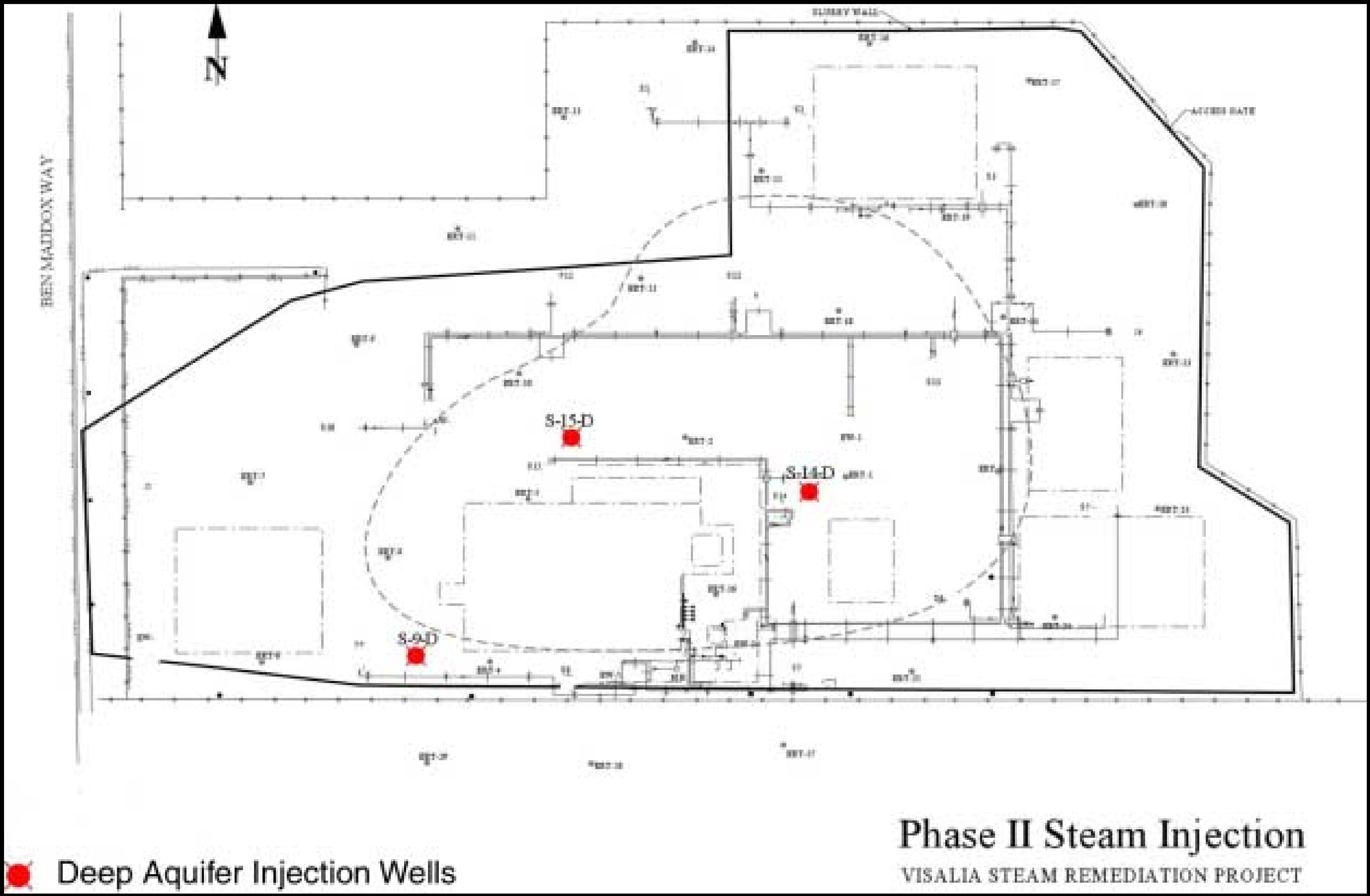
Phase II Steam Injection Cross-Section

The Visalia Steam Remediation Project



Phase II Deep Well Locations

The Visalia Steam Remediation Project



Phase II Results

The Visalia Steam Remediation Project

- Additional **410,000 lbs** DNAPL Removed
  - Project total ~1.3 million lbs
  - 65% of groundwater extraction wells are clean
  - Steam injection continues to remove
- **Lessons Learned**
  - Vertical steaming effectively removed creosote from the Intermediate Aquitard
  - Optimized hot liquid pumping
  - Optimized injection/extraction design and operation
  - Optimized steamflood reservoir management

Costs at Visalia

The Visalia Steam Remediation Project

- Total Project Cost: **$21.5** million 1996 through 2000
- Unit Cost per Cubic Yard of Soil Treated
  - Actual costs **$57**
  - With lessons learned **$38**
  - Solvent and fuels **$25**
- Comparative Cost per Gallon of Creosote Removed
  - Pump-and-treat **$26,000**
  - DUS **$130**
- Estimated Time to Remove 1.3 Million Pounds of Creosote
  - Pump-and-treat **3,250 years**
  - DUS **3 years**

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VOC Remediation Utilizing an Existing On-Site Boiler for Steam Enhanced Soil Vapor Extraction

Site Background

Boiler Case Study

- Former manufacturing facility in the New England area, operated 1950s - 1997
- VOC Source
  - Releases of styrene and ethylbenzene in a former tank farm area and a containment basin area
  - Tanks removed in 1998
  - Soil contamination up to 13,000 ppm styrene and 8,500 ppm ethylbenzene
  - Groundwater contamination up to 87 ppm styrene and 43 ppm ethylbenzene
  - LNAPL reported in past investigations

Site Hydrogeology

Boiler Case Study

- Site is located in a river floodplain
- 0 - 7 ft: Fill material in some areas
- 0 - 28 ft: Fine sand and silt with occasional gravel layers and bands of silty clay
- 28 - 41 ft: Coarse to fine sand with traces of gravel or silt
- 41 - 60 ft: Fine sand with traces of silt
- >60 ft bgs: Bedrock
- Water table: 15-25 ft bgs

Remedial Approach

Boiler Case Study

- Thermally-enhanced vapor extraction in vadose zone
- Air sparging in the saturated zone
- Steam injection and vapor extraction screen depths determined by PneuLog™ testing in the field at time of installation
- Two treatment areas
  - 160 ft x 90 ft and 110 ft x 90 ft to a depth of 25 ft
- Conducted bench-scale test December 1997 to determine feasibility of steam heating

System Installation (10/99-3/00)

Boiler Case Study

- Former Tank Area
  - Vapor extraction
    - Via ten 2-in.-diameter nested SVE wells, screened at 4-9 ft and 12-17 ft and four 4-in.-diameter SVE wells installed for PneuLog™ testing
  - Steam injection
    - Via 11 nested steam wells, screened at 5-8 ft and 12-15 ft
  - 18 air sparge wells
    - 11 of which are nested with the steam wells, screened at 22-25 ft
  - 3 temperature thermocouple arrays
  - 4 nested piezometers
    - Screened at 4-6 ft and 8-11 ft

System Installation (Cont.)

Boiler Case Study

- Former Containment Area
  - Vapor extraction
    - Via 20 2-in.-diameter nested SVE wells, screened at 4-9 ft and 12-17 ft and three 4-in.-diameter SVE wells installed for PneuLog™ testing
  - Steam injection
    - Via 13 nested steam wells, screened at 5-8 ft and 12-15 ft
  - 16 air sparge wells
    - 13 of which are nested with the steam wells, screened at 22-25 ft
  - 3 temperature thermocouple arrays
  - 4 nested piezometers
    - Screened at 4-6 ft and 8-11 ft

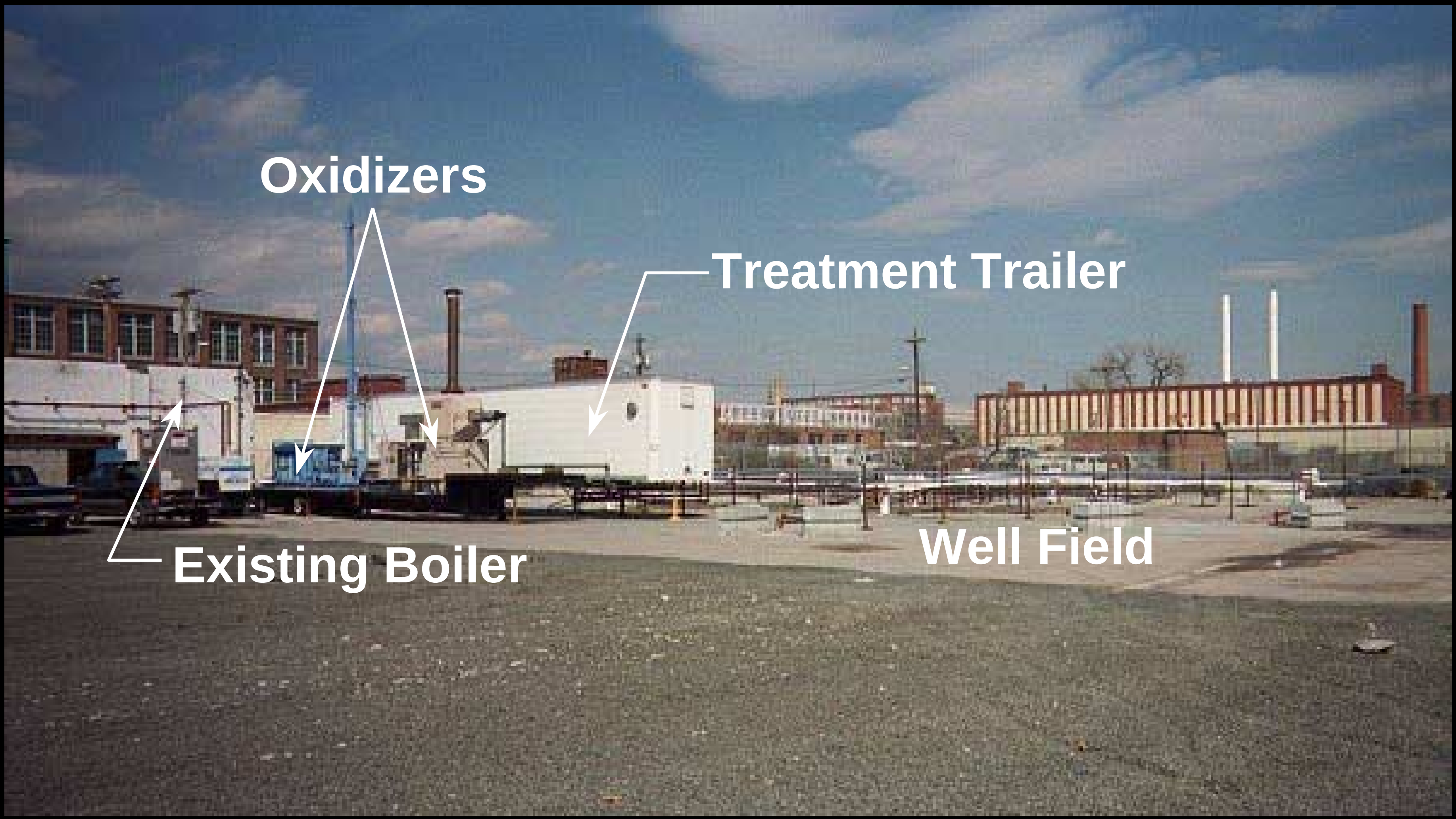
Treatment Equipment

Boiler Case Study

- 2 rotary lobe blowers for SVE system
  - 100 hp, 900 scfm @ 11.5" Hg
- 1 rotary lobe compressor for AS
  - 25 hp, 225 scfm @ 14.5 psi
- Existing boiler w/15 psi PRV
  - 150 hp, 150 psi, 5 mBTU/hr
- 325-gal moisture separator
- 300-gal diffuser tank
- 2 55-gal GAC canisters
- 2 thermal oxidizers
  - 800 cfm, 600 cfm

Site Layout

Boiler Case Study



System Installation

Boiler Case Study

Cost Summary

Boiler Case Study

- Design/Fabrication/Installation and Start-up: $850,000
- Estimated O&M, 1 year, $180,000
- Soil volume treated based on surface area of wells and depth: 22,500 cy
- Cost per cy: $45.80

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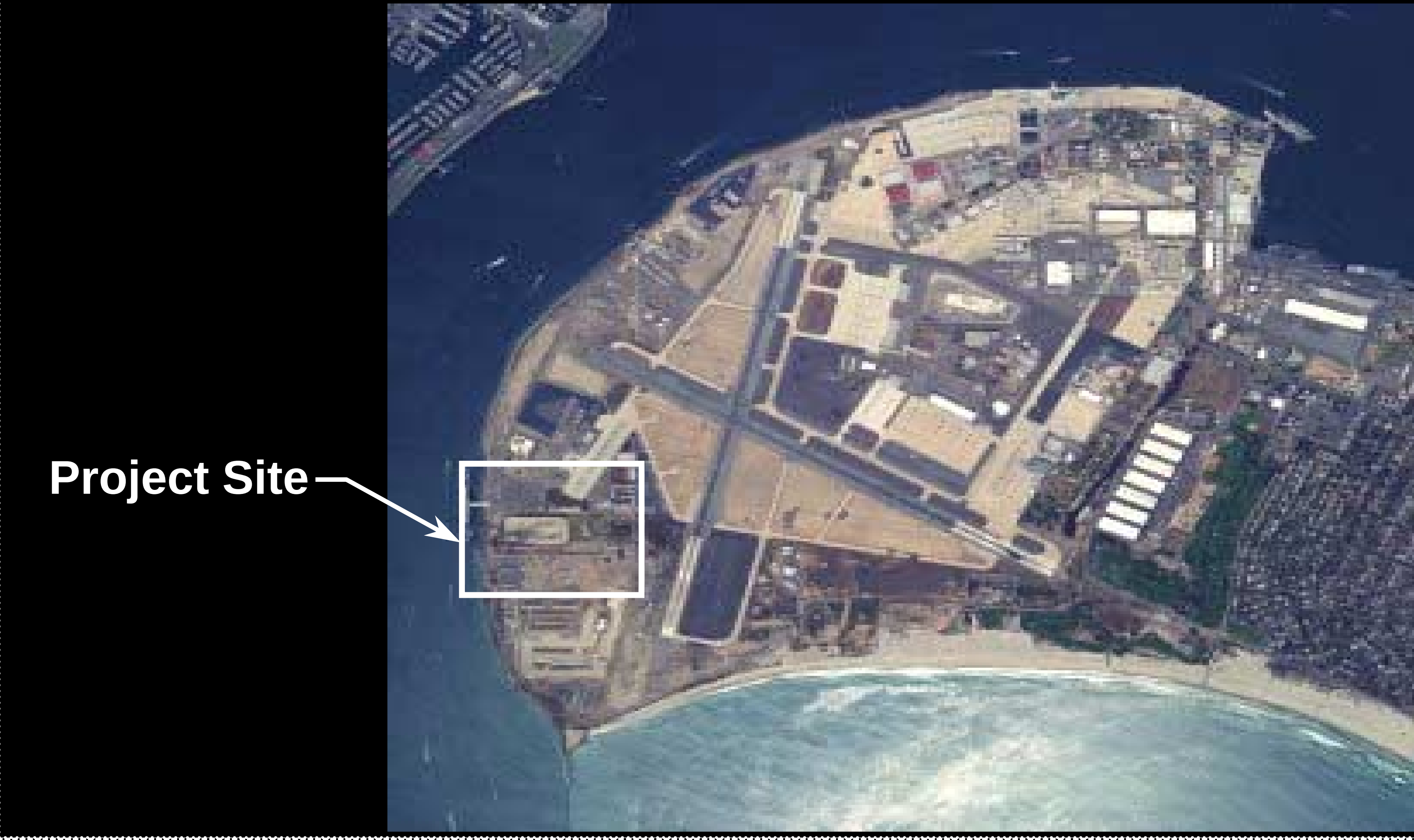
Soil Remediation Using Thermal Enhanced Soil Vapor Extraction

OHM Remediation Services Corp

Site Vicinity Photo

NAS North Island, CA



Project Background

NAS North Island, CA

- March 1997: 3,000 scfm SVE system initiated
- Objective to REDUCE MASS of volatile organic compounds (VOCs) in soil
- Trichloroethene (TCE) identified as a major risk driver
- Intended as interim action to reduce risk for future full-scale remediation workers
- Groundwater investigations and studies still ongoing

3,000 SCFM SVE System

NAS North Island, CA

Initial Soil Remediation by SVE

NAS North Island, CA

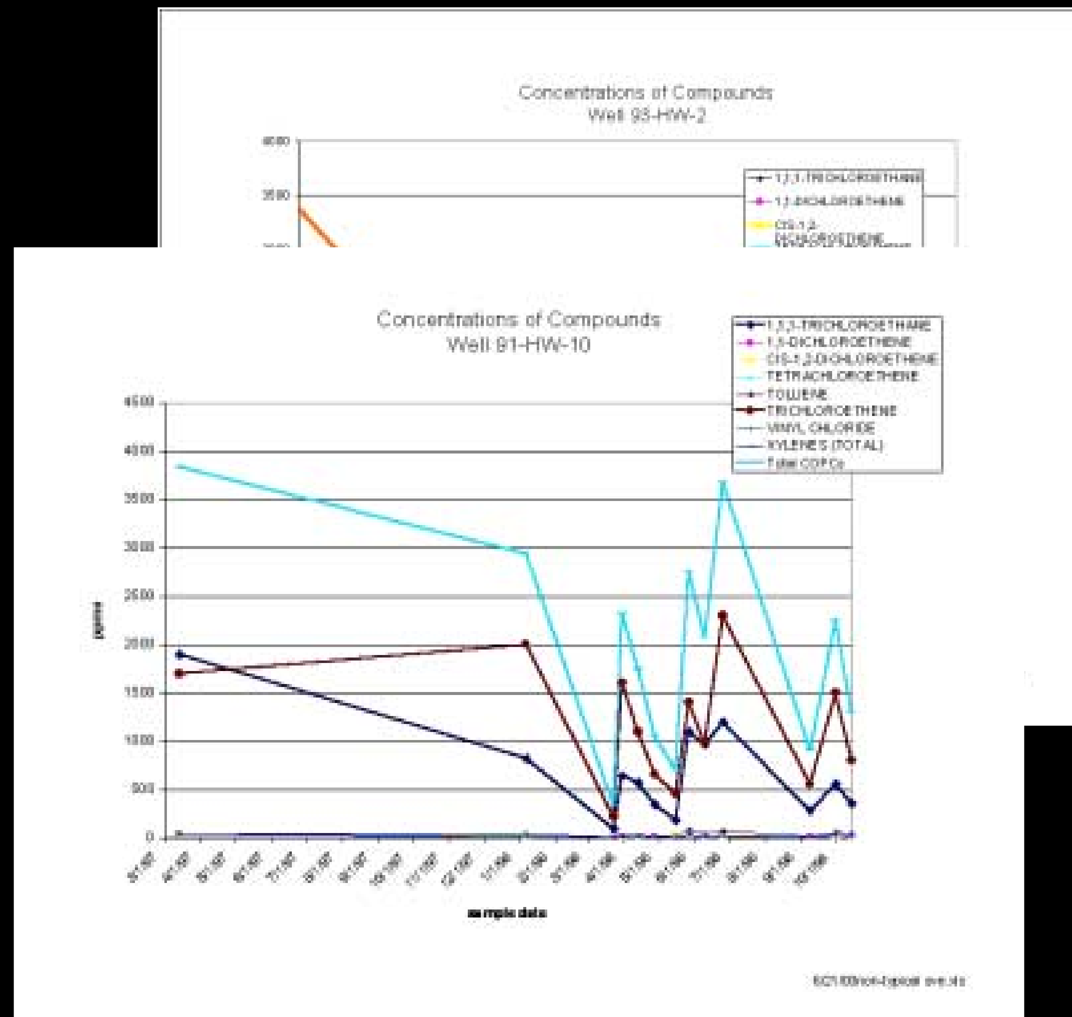
- System operated for 26 months
- Removed over 80,000 lbs of mixed VOCs
- Non-typical SVE response

SVE System Response

NAS North Island, CA

- Typical SVE System Response

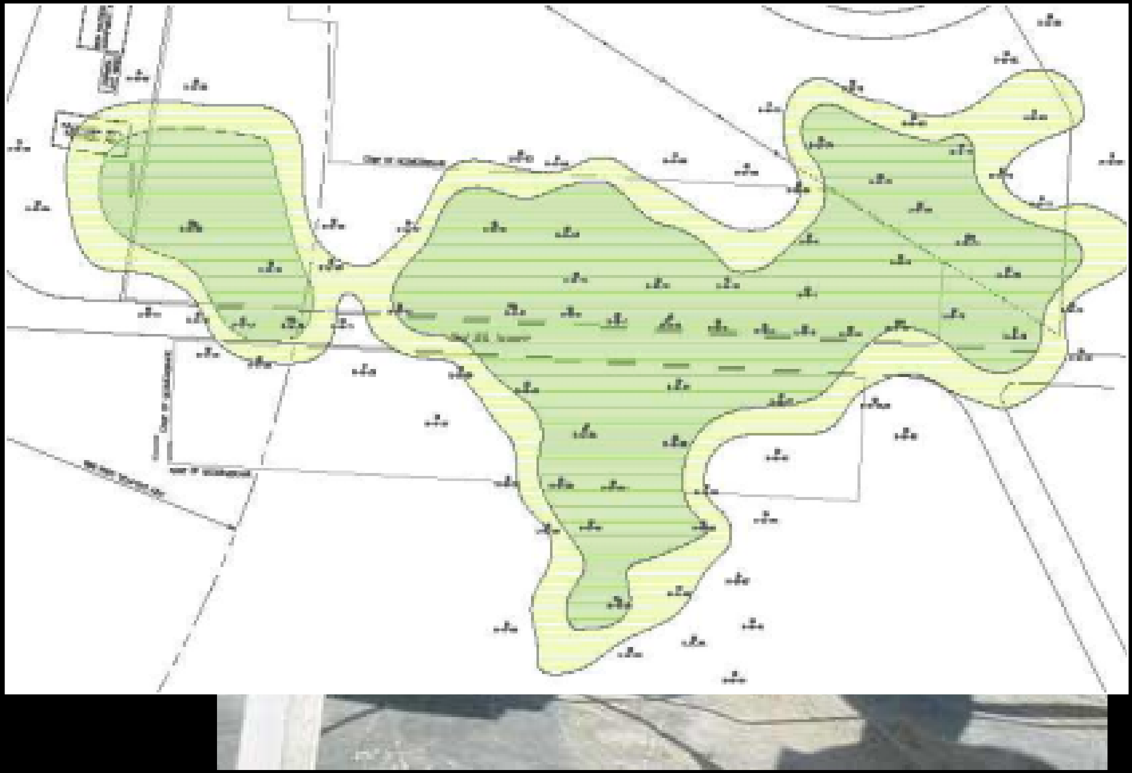
- Site 9 SVE System Response



Additional Investigation

NAS North Island, CA

- In late 1998 Navy Public Works Center (PWC) assisted with investigations
- Free product (JP-5) delineated using Laser-Induced Fluorescence (LIF)
- JP-5 commingled with approximately 20% by weight TCE



Additional Investigation Conclusion

NAS North Island, CA

SVE Alone Is Not A Cost-Effective Method

Pilot-Scale Thermal Enhancement

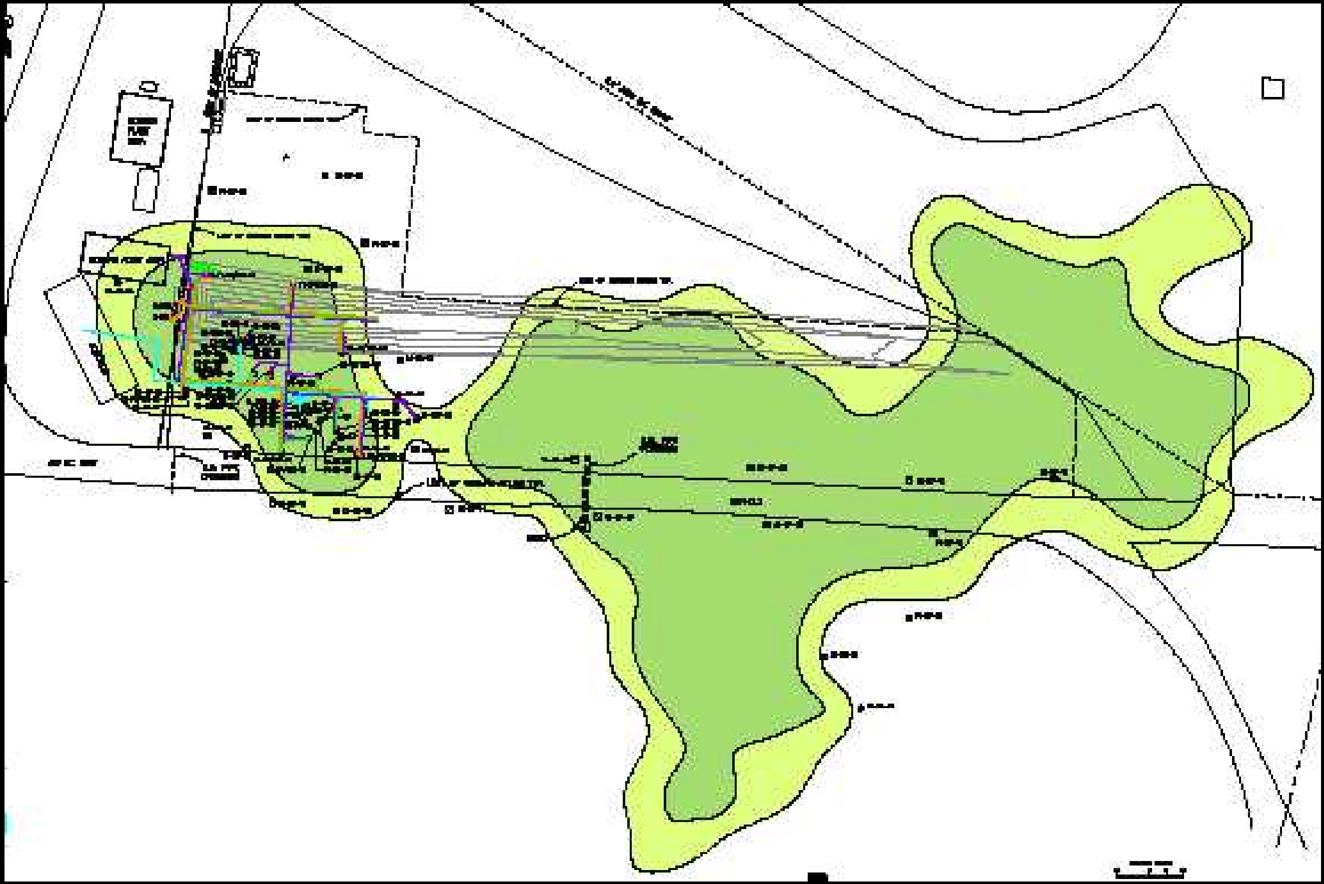
NAS North Island, CA

- Evaluated options to *enhance* existing equipment
  - Minimize additional documentation
  - Reduce overall project costs
- Thermal enhancement and product skimming
  - Volatilize TCE from free product; capture using SVE
  - Remove free product directly using skimming pumps
  - Increased temperature reduces viscosity and increases flow toward capture wells

Thermal Enhanced Pilot System

NAS North Island, CA

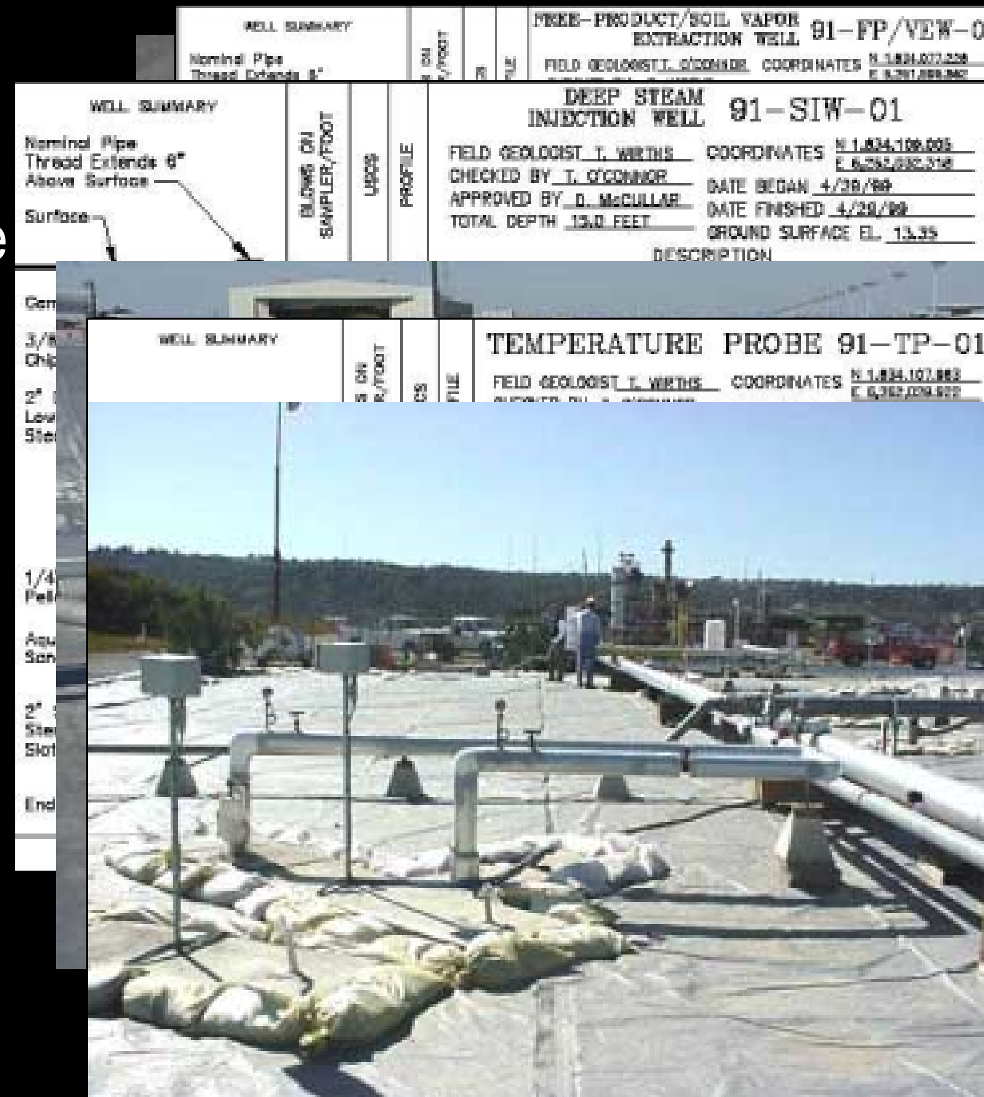
- Pilot-scale system installed in mid-1999



System Components

NAS North Island, CA

- Product Skimming/SVE
  - 10 dual-phase extraction wells
  - In-well pumps and conveyance piping
  - SVE from each well
- Steam Injection
  - 3 wells
  - 100 to 150 lbs/hr
- Temperature data collection
  - 10 sets of 5 nested thermocouples
  - Continuous data logger



Thermal Enhanced SVE: Pilot Operation

NAS North Island, CA

- September 1999 to May 2000
  - Over 2,000 gallons free product removed via skimming
  - Over 500 gallons TCE removed via vapor extraction
- Compared to NON-enhanced SVE, thermal enhancement resulted in over 5 times the removal rate
  - Enhanced: 0.16 pound per month per square foot
  - SVE: 0.028 pound per month per square foot
- Decision to expand to full-scale

Some Pilot-Scale Findings

NAS North Island, CA

- Steam injection ROI
  - Advective: 8 to 15 ft
  - Conductive: measured out to 40 ft
- Increases temperature in extracted free product and groundwater; less in vapor

Summary

NAS North Island, CA

- Thermal enhancement was shown cost-effective for Site 9
- Mass removal increased by more than 5 times over SVE alone
- Proceed to full-scale system: September 2000

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    - **Six-Phase Heating (SPH)**
  - Electrical Conductive Heating

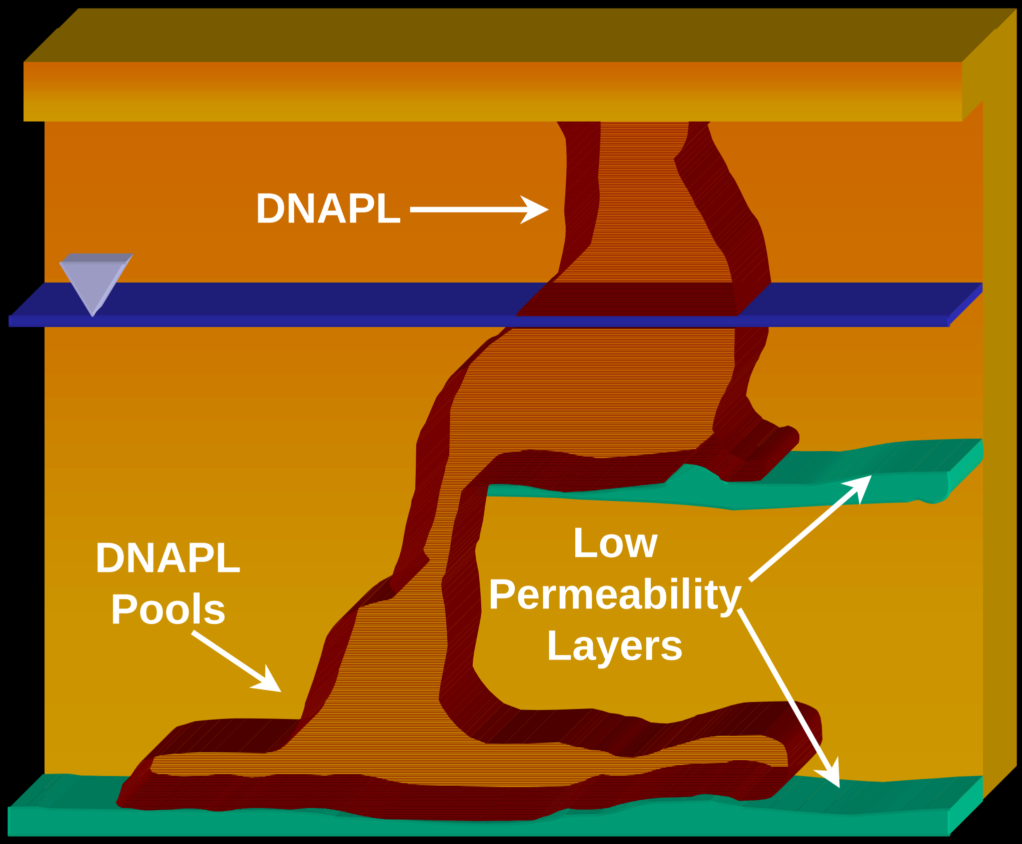
What is Six-Phase Heating?

Six-Phase Heating

- Takes common three-phase electrical energy and inputs it to the subsurface through electrodes
- Once in the subsurface, the electrical energy resistively heats soil and groundwater
- Electrodes can be placed vertically to any depth or may be placed horizontally
- Contaminants are removed by direct volatilization and in situ steam stripping

DNAPL Contamination

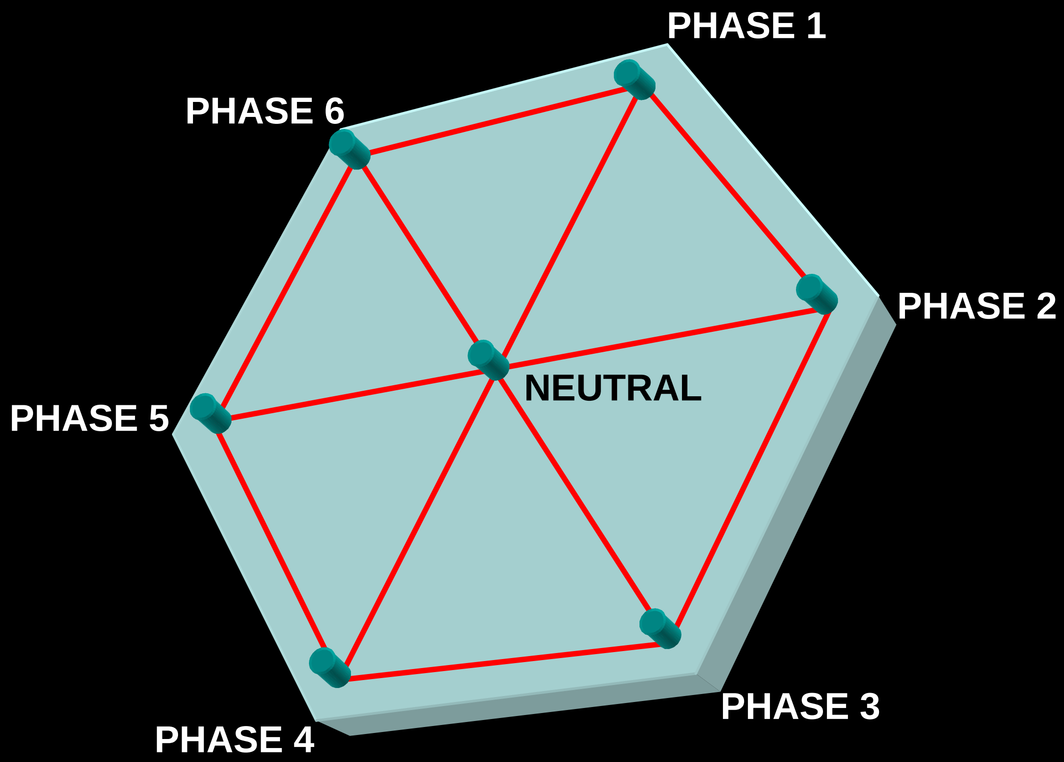
Six-Phase Heating



How Does Six-Phase Heating Work?

Six-Phase Heating

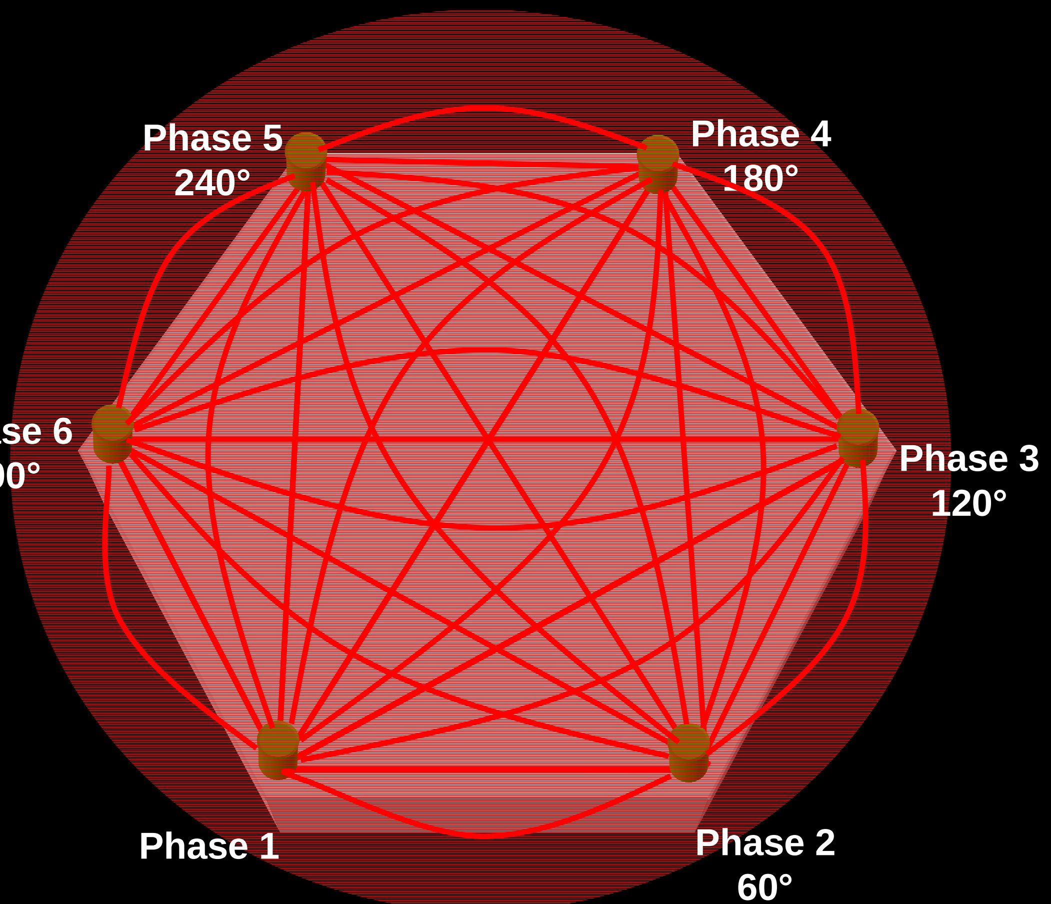
- The Six-Phase Array (SPA™) is made up of 6 electrodes
- A 7th "Neutral" electrode in the center can serve as a vent
- A typical array diameter is 30-80 ft (up from 20-40 ft)



Six-Phase Heating Geometry

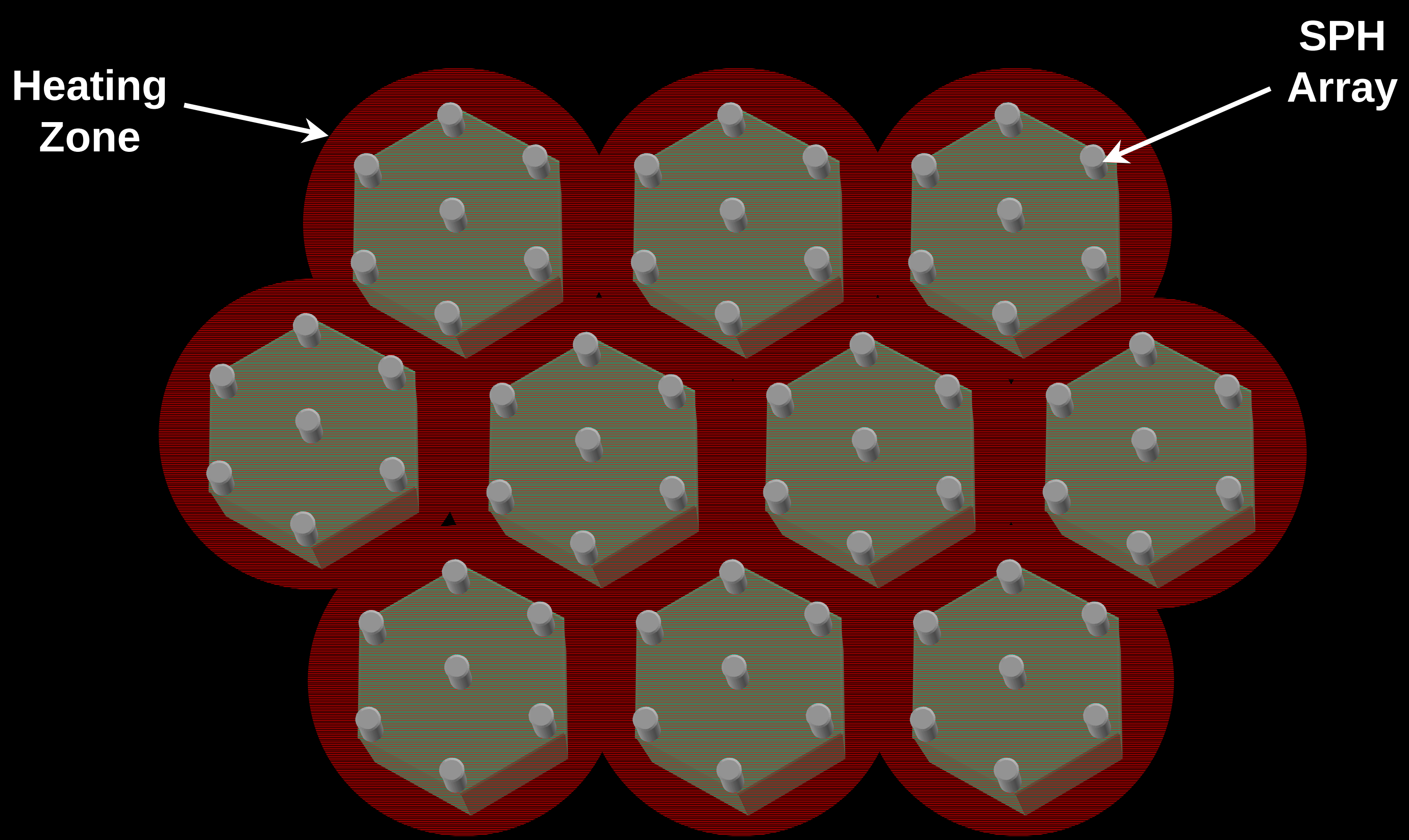
Six-Phase Heating

Heated Zone is 40% larger than array diameter



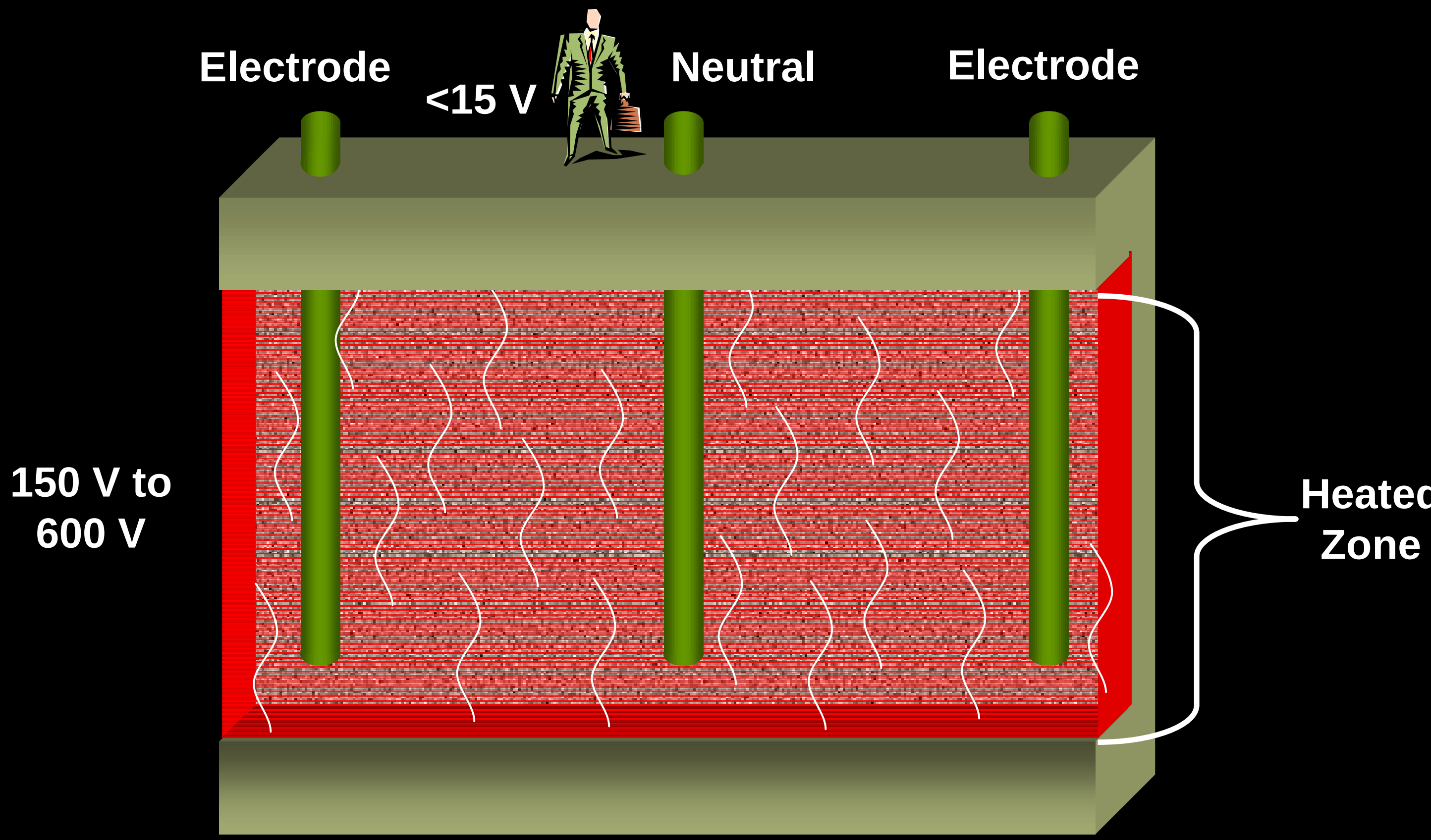
Full-Scale Implementation: Multiple Arrays

Six-Phase Heating



In Situ Steam Generation

Six-Phase Heating

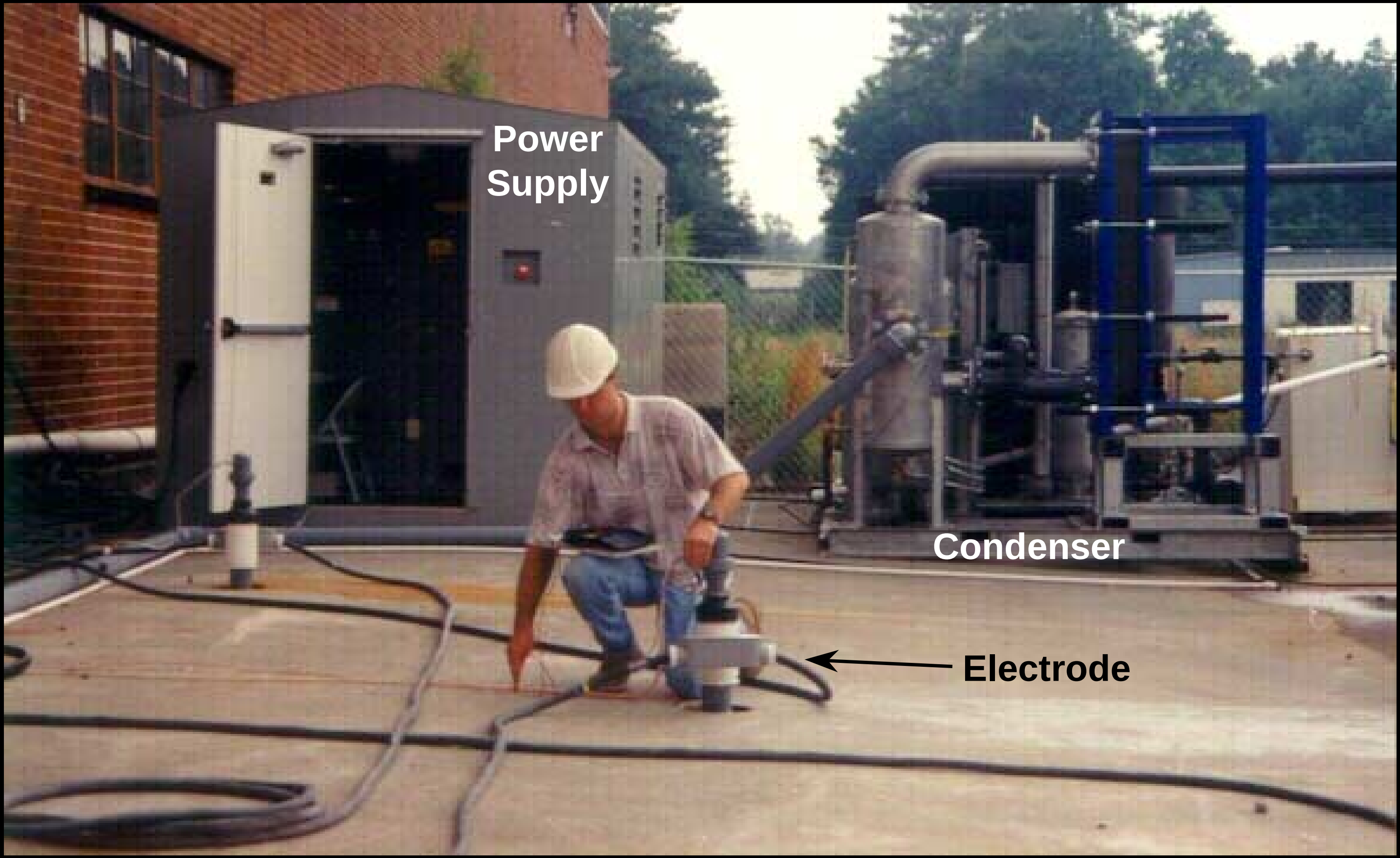


1. Soil grains act as individual resistors

2. Steam generation is uniform throughout the heated zone

Verifying Safe Voltages

Six-Phase Heating



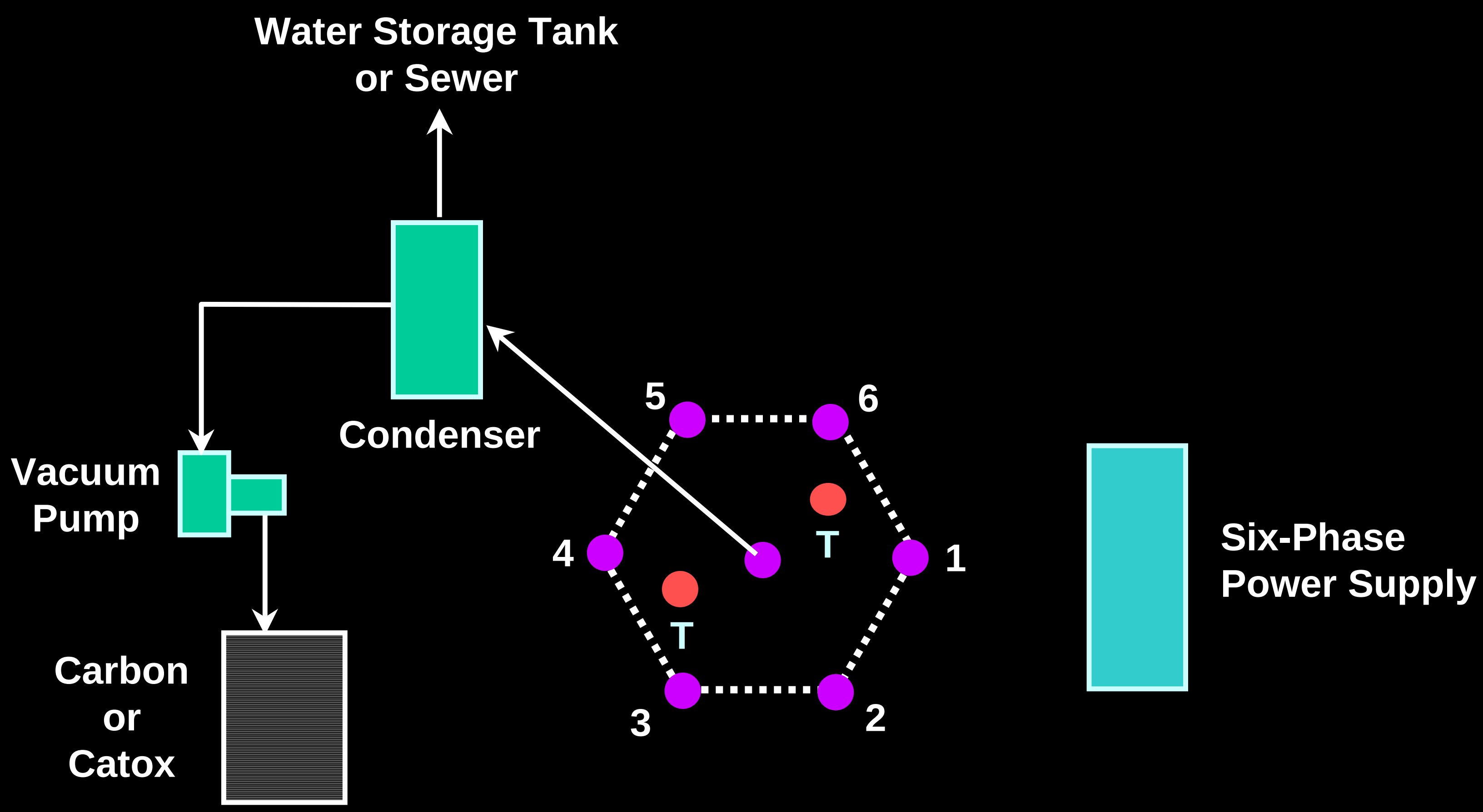
SPH Applications

Six-Phase Heating

- DNAPL cleanup by aquifer heating
- LNAPL cleanup by smear zone heating
- Low permeability lithologies
- Heterogeneous lithologies
- Bioremediation enhancement
- Heavy hydrocarbon mobilization
- Rapid remediation

Vapor Recovery System

Six-Phase Heating



SPH Power Supply

Six-Phase Heating

SPH Example Project History

Six-Phase Heating

- Savannah River, SC: Low perm soil demo
- Dover AFB, DE: DNAPL demo
- Fort Richardson, AK: Recalcitrant VOC demo
- Fort Wainwright, AK: Bio/cold region demo
- Skokie, IL: Full-scale DNAPL closure
- Cincinnati, OH: LNAPL demo
- Seattle, WA: Brownfields cleanup to MCLs
- Atlanta, GA: Viscous fuel recovery
- Cape Canaveral, FL: DNAPL "fly-off"

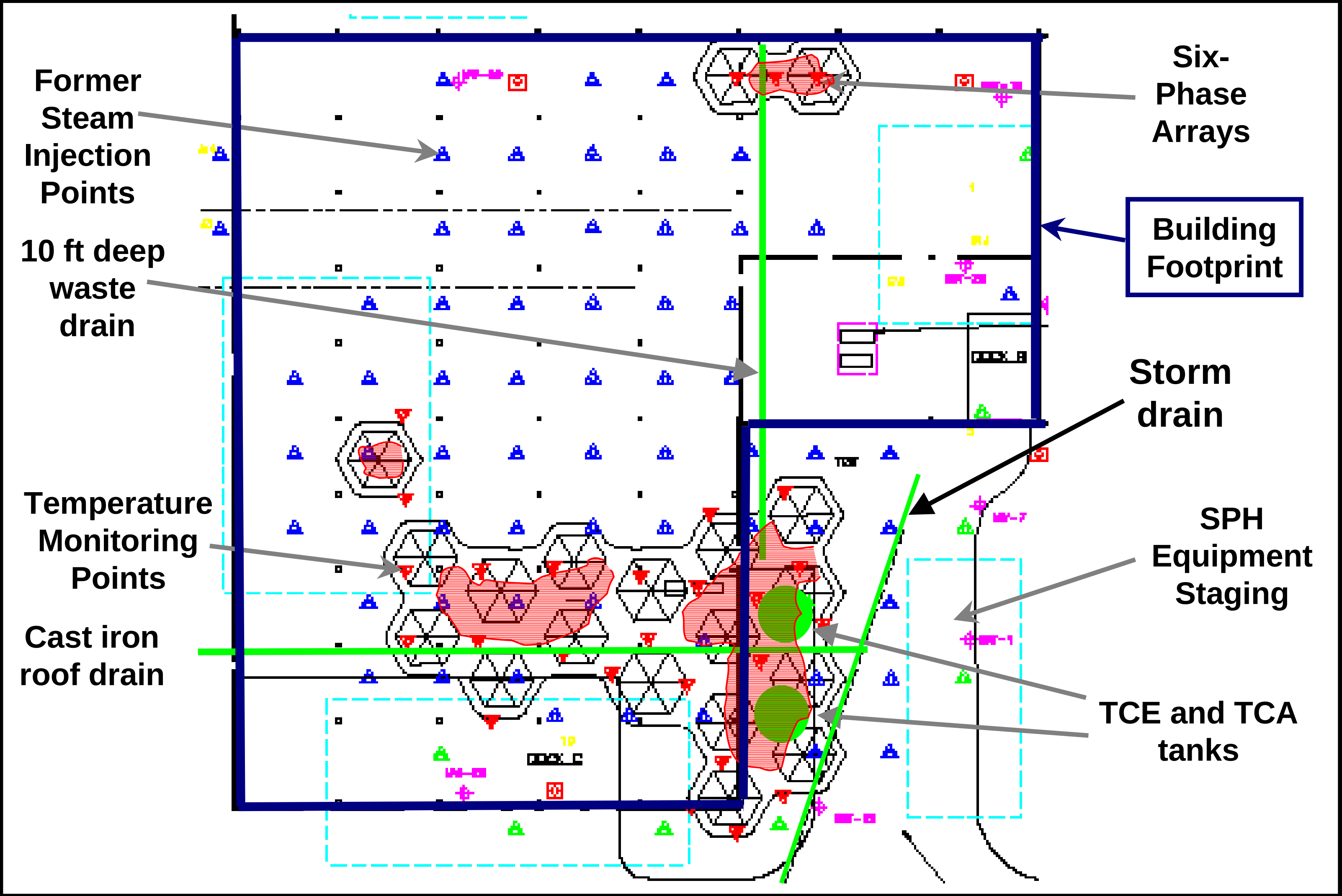
Full-Scale DNAPL Cleanup: The Problem

Six-Phase Heating

- DNAPL (TCE & TCA) covering 1 acre of an industrial site
- Steam injection had been applied for 5 years and removed 30,000 lbs of TCE & TCA
- DNAPL pools still remained in four areas, mostly under a large warehouse building
- Goal: Reach Tier III RBCA Cleanup Levels over entire site

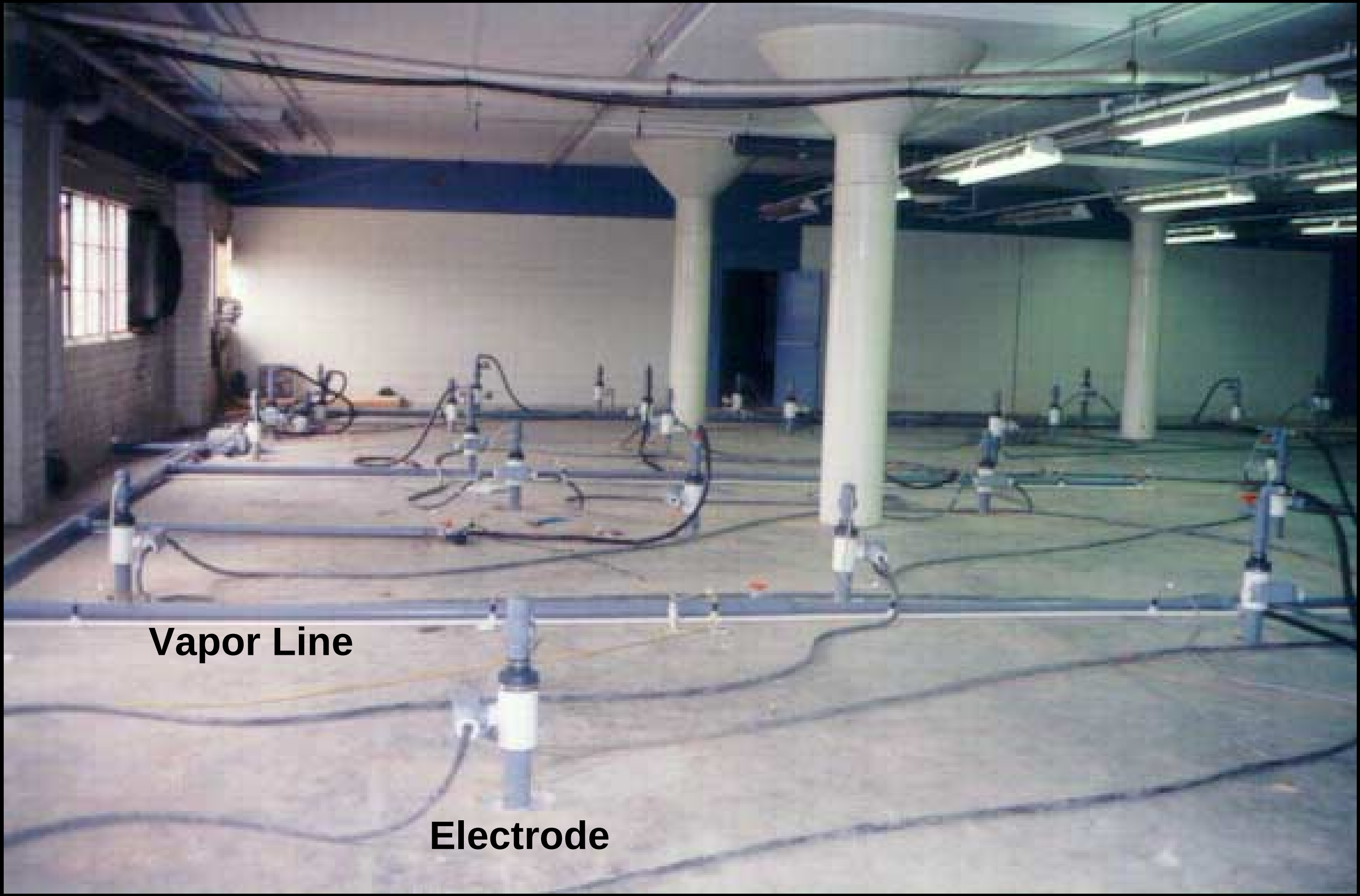
Full-Scale DNAPL Cleanup: Site Map

Six-Phase Heating



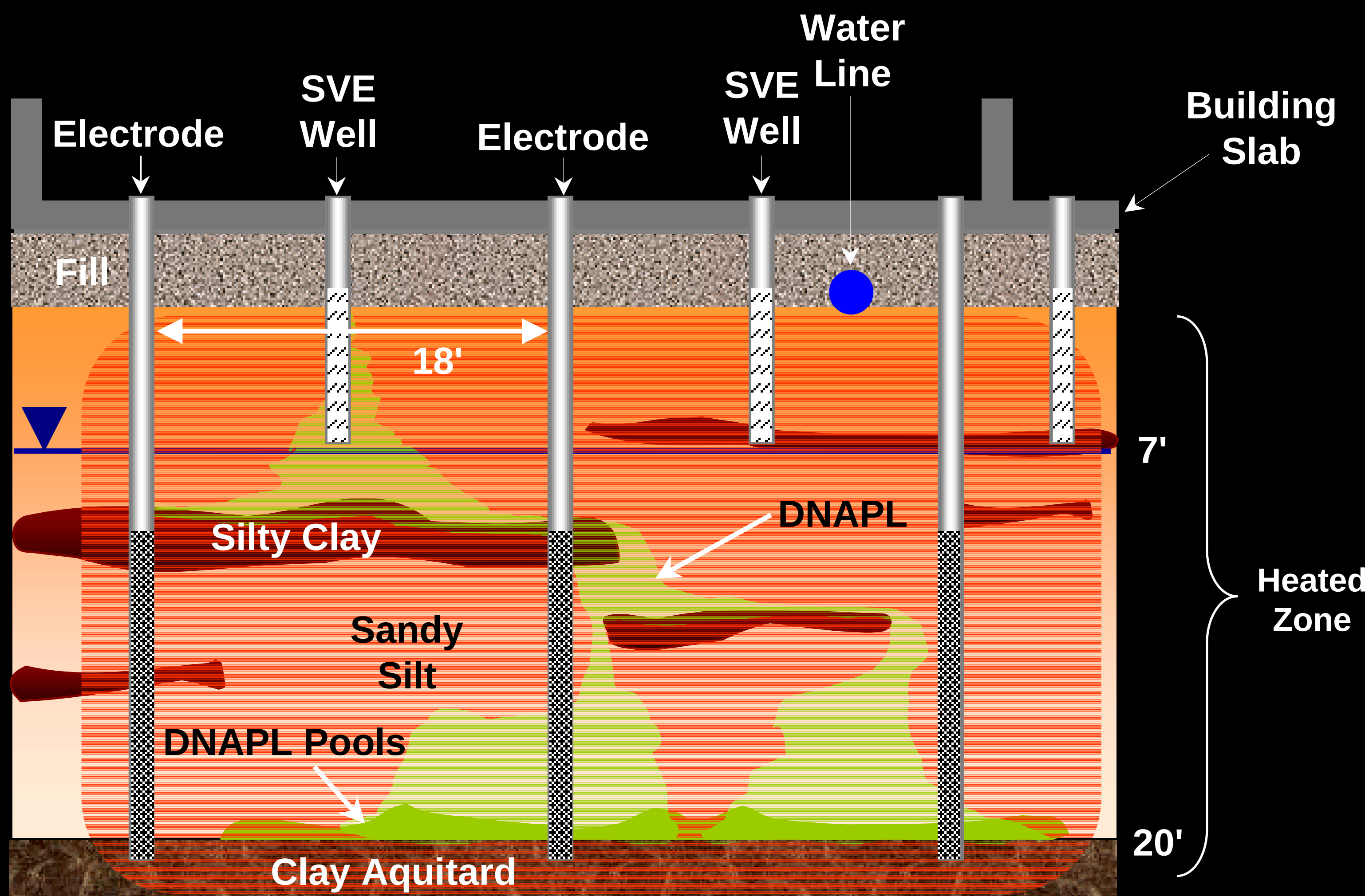
SPH Remediation Beneath a Building

Six-Phase Heating



Full-Scale DNAPL Cleanup: Subsurface Cross-Section

Six-Phase Heating



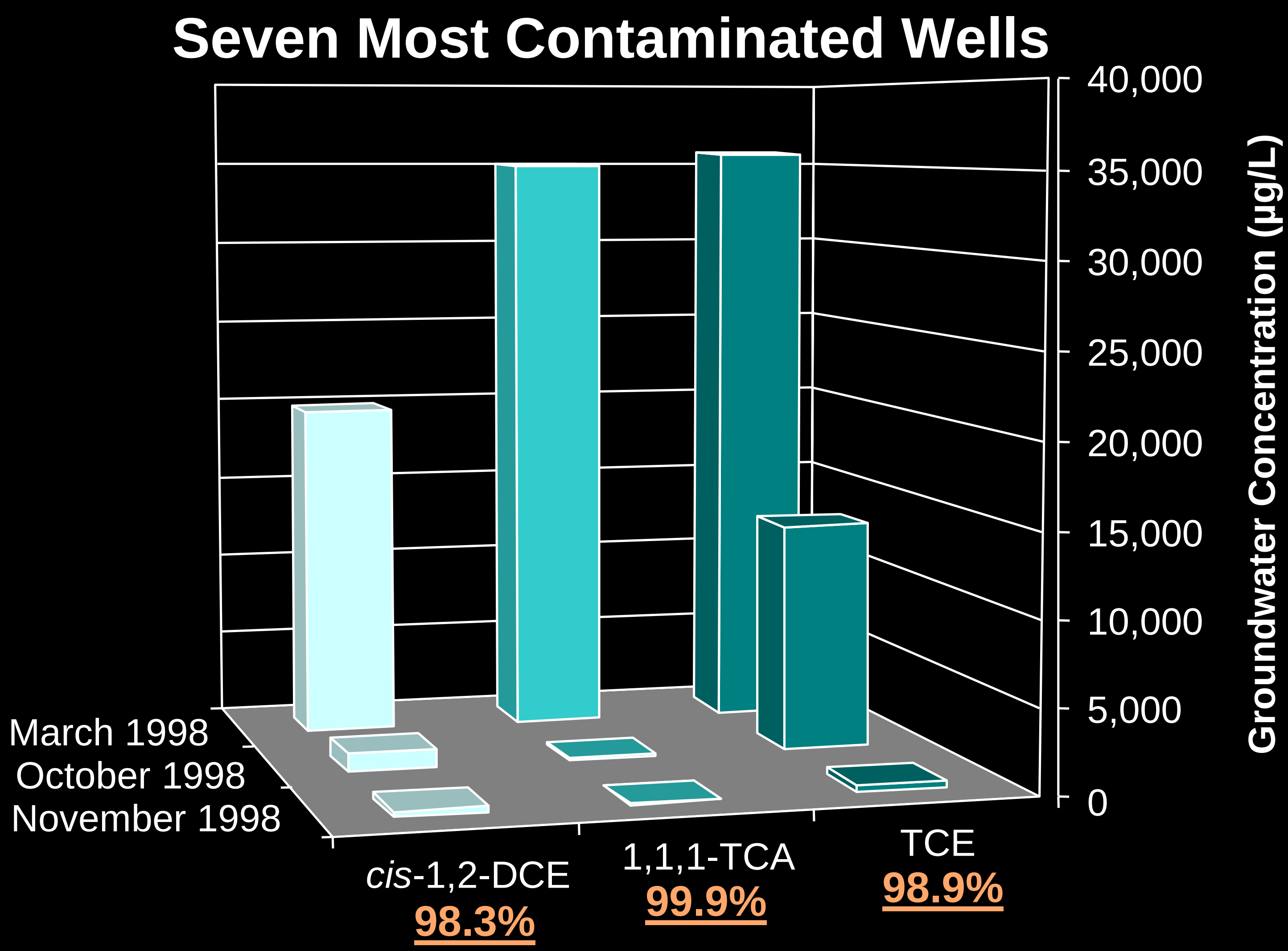
Full-Scale DNAPL Cleanup: Operations & Results

Six-Phase Heating

- Operations
- Heating (107 electrodes) started June 4
- Aquifer reached boiling in 60 days
- Maintained above the boiling point of TCE (73°C) for the next 3 months
- Results
- Tier III levels by late November 1998; the site is now closed
- >15,000 pounds of VOCs removed

Average Groundwater Concentrations

Six-Phase Heating



Full-Scale DNAPL Cleanup: Cost & Performance Data*

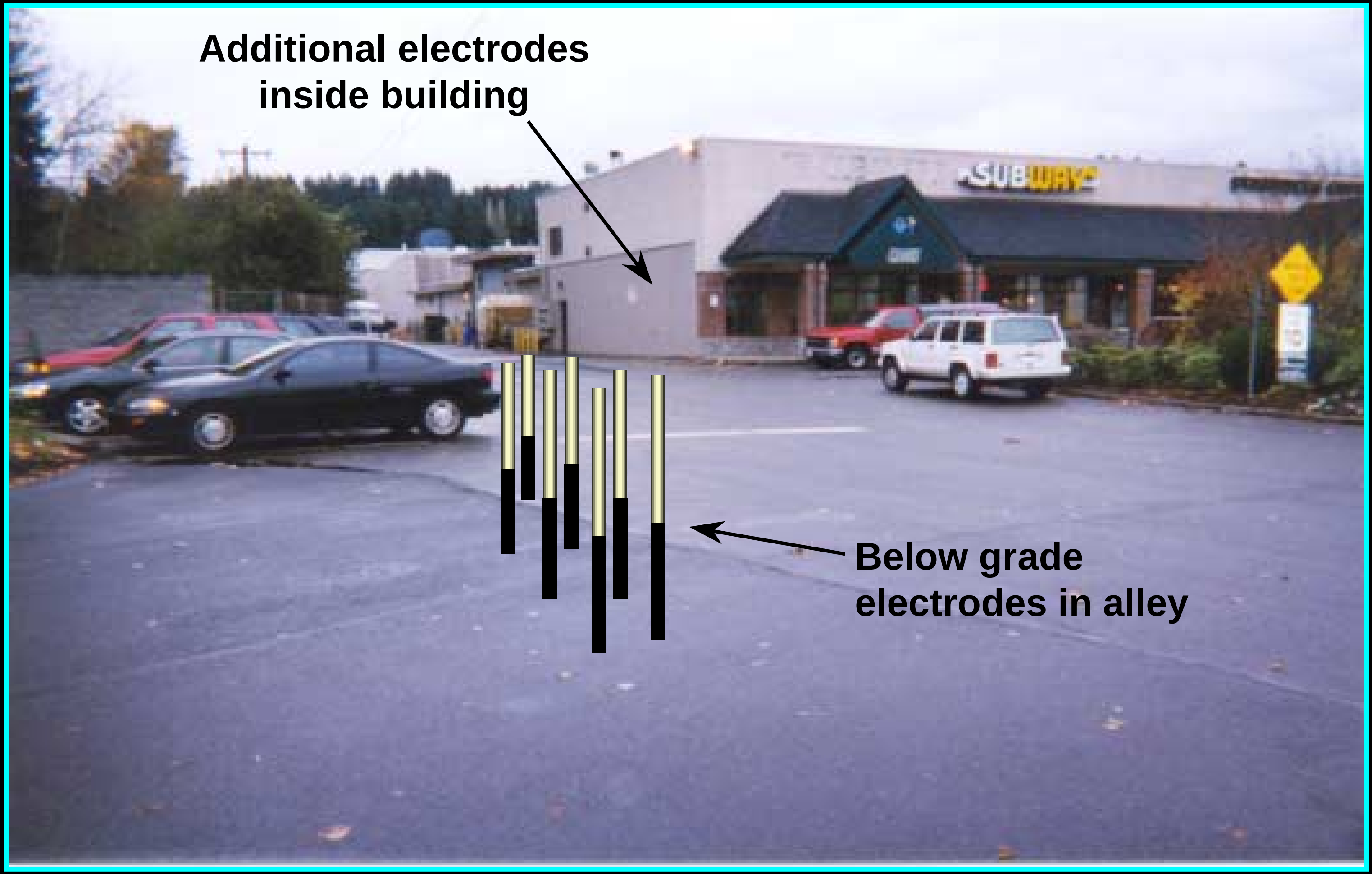
Six-Phase Heating

- **Remediation Plan**
  - Remove all DNAPL & achieve Tier III levels
- **Effectiveness**
  - Total SPH operations took 18 weeks, five days
  - Treated approximately 23,000 cy
  - Since completing SPH, average groundwater VOC concentrations have continued to decrease
- **Costs**
  - Total SPH project costs were $32/cy
  - The total includes electrical costs of $6.50/cy

*The EPA has prepared a third party cost and effectiveness report similar to this data

Seattle Remediation to MCLs

Six-Phase Heating



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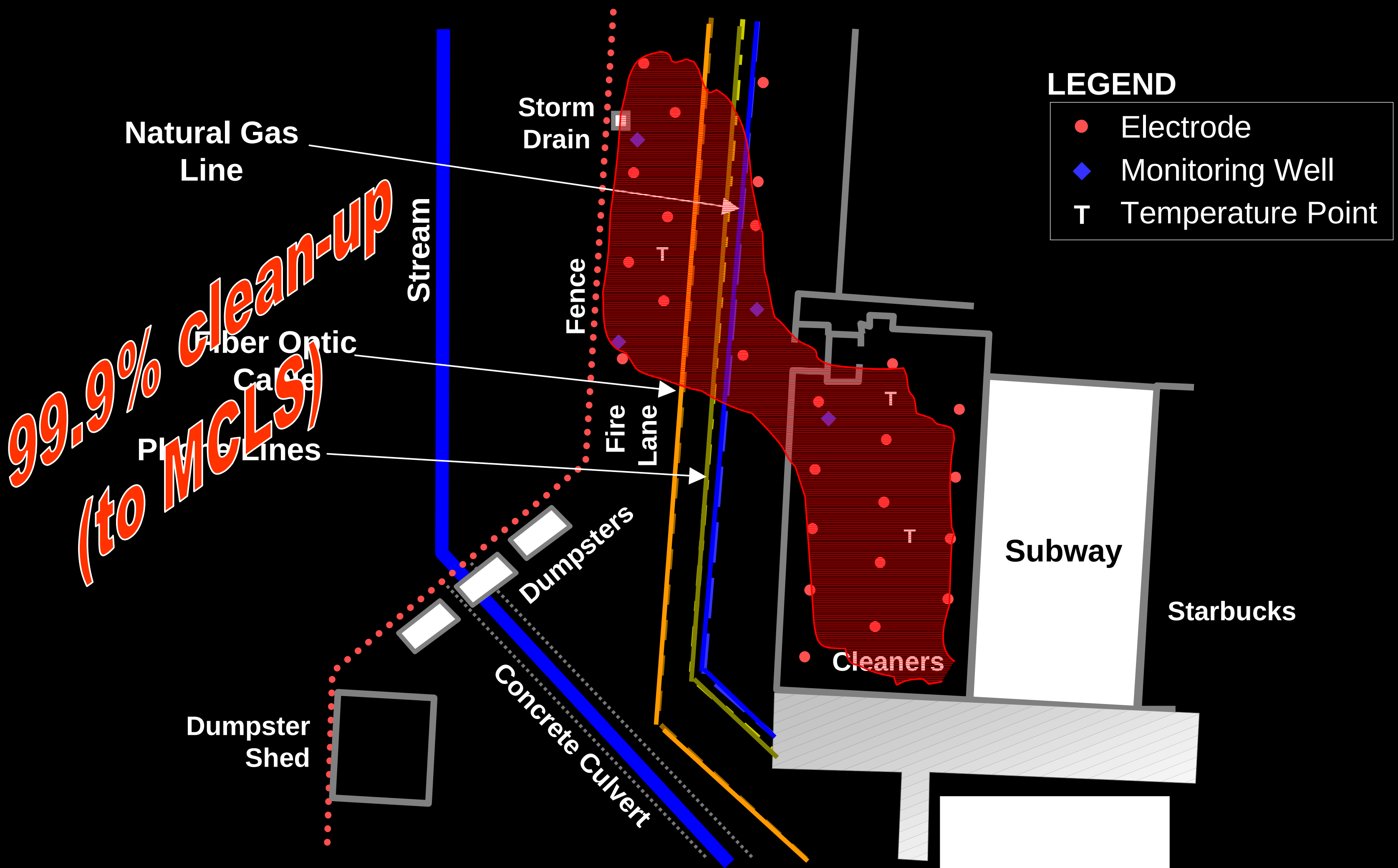
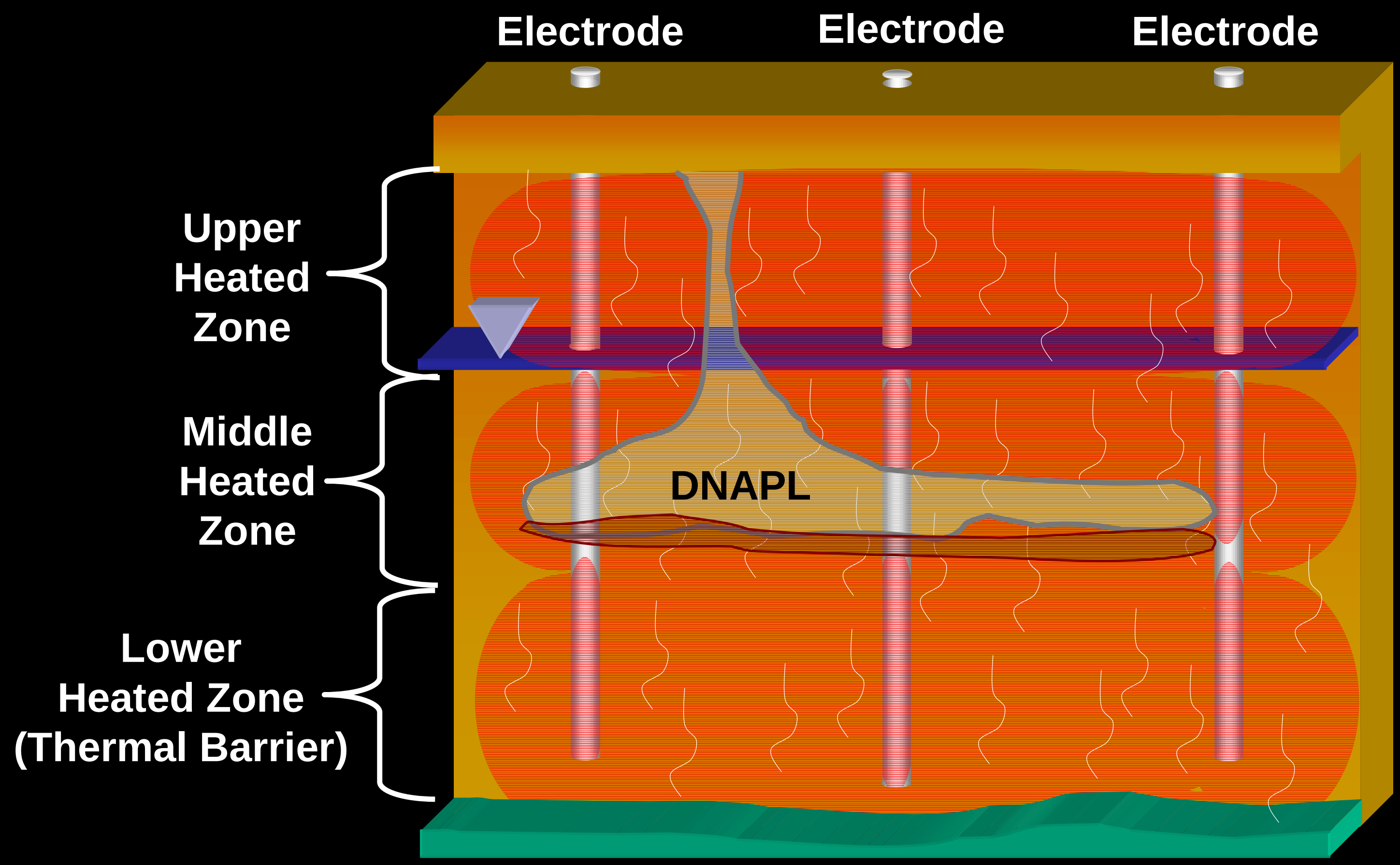
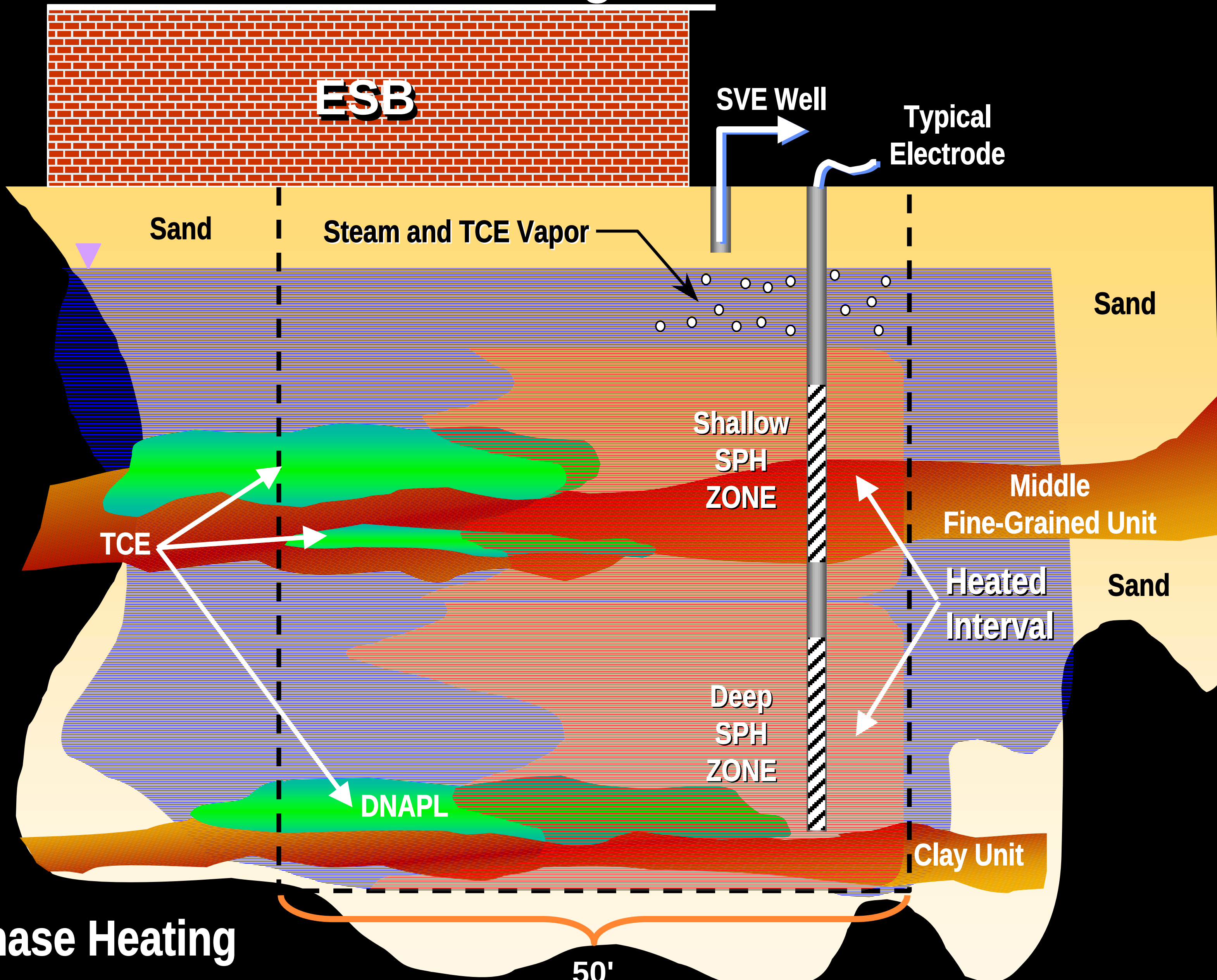


SPH Targeted Heating Zones

Six-Phase Heating



IDC SPH Cross Section Diagram



Six-Phase Heating

Costs

Six-Phase Heating

Site	Contaminant	Quantity	Cleanup Goal	Unit Cost
Chicago, IL	PCE	12,000 cy 40 ft bgs	75% removal	$80/cy
Skokie, IL	TCE/TCA	35,000 cy silt, clay lenses	99% removal	$32/cy
Portland, OR	TCE	21,500 cy silt/gravel 65 ft bgs	99.9% removal	$42/cy
Waukegan, IL	MeCl	16,000 cy sand, silt, clay 39 ft bgs	24 mg/kg	$61/cy

Advantages

Six-Phase Heating

- Heating is uniform, no bypassed regions
- Heating is rapid
- Steam is produced in situ
- Preferentially heats tight soil lenses and DNAPL hot spots
- Cost effective: $30 to $90 per cubic yard

Outline of Presentation

In Situ Thermal Treatment

- Practical/Policy Overview
- General Principles of In Situ Thermal Treatment
- **Specific Technologies and Case Studies**
  - Steam Enhanced Extraction
  - Electrical Resistance Heating
  - **Electrical Conductive Heating**
    - **In Situ Thermal Desorption (ISTD): Remediation of Contaminated Soil by Thermal Conduction and Vacuum**

ISTD Process Steps

ISTD

- Thermal conduction into soil
- Vaporization of fluids within soil
- In situ oxidation and pyrolysis
- Collection of vapors
- Surface treatment of vapors

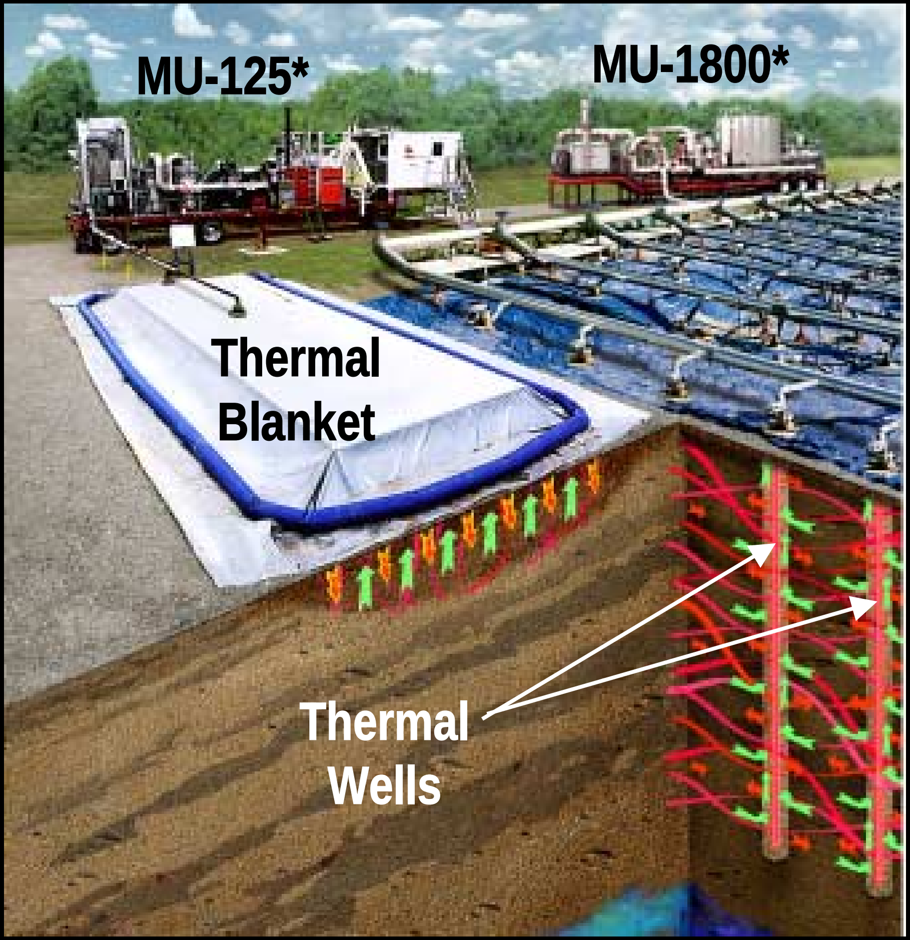
Thermal Conduction Heating

ISTD

- Heats Soil Uniformly
  - Vertical Profiles
  - Areal Coverage
- Dries Soil and Creates Permeability
- Attains Very High Soil Temperature (if needed)

ISTD: Simultaneous Application of Heat and Vacuum

ISTD



*These units are currently available

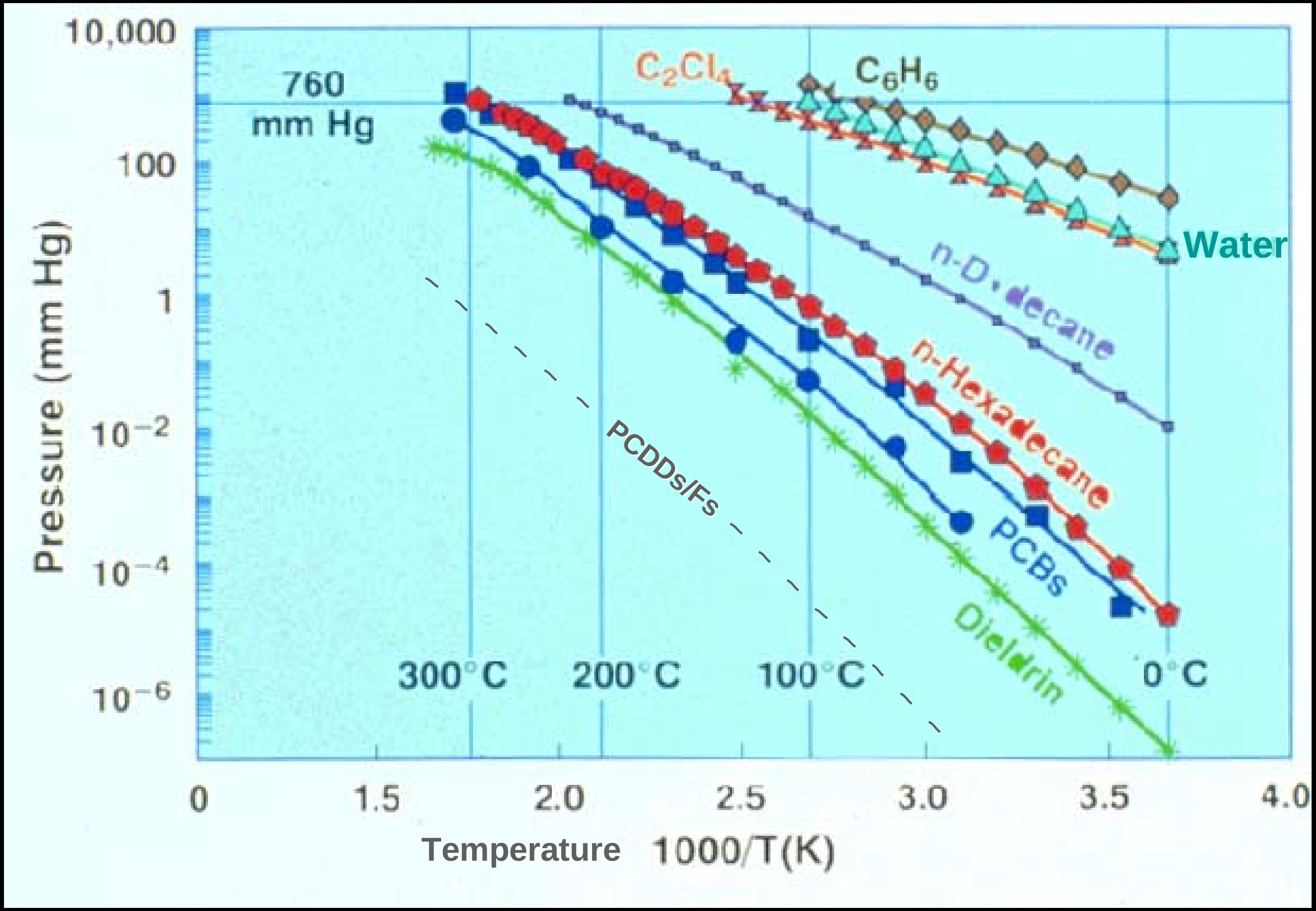
Off-Gas Treatment System

ISTD

- Cyclone Separator
- Flameless Thermal Oxidizer
  - Thermatrix
  - $\geq$ 99.99% DRE
- Air-to-Air Heat Exchanger
- Scrubber
- Carbon Adsorber

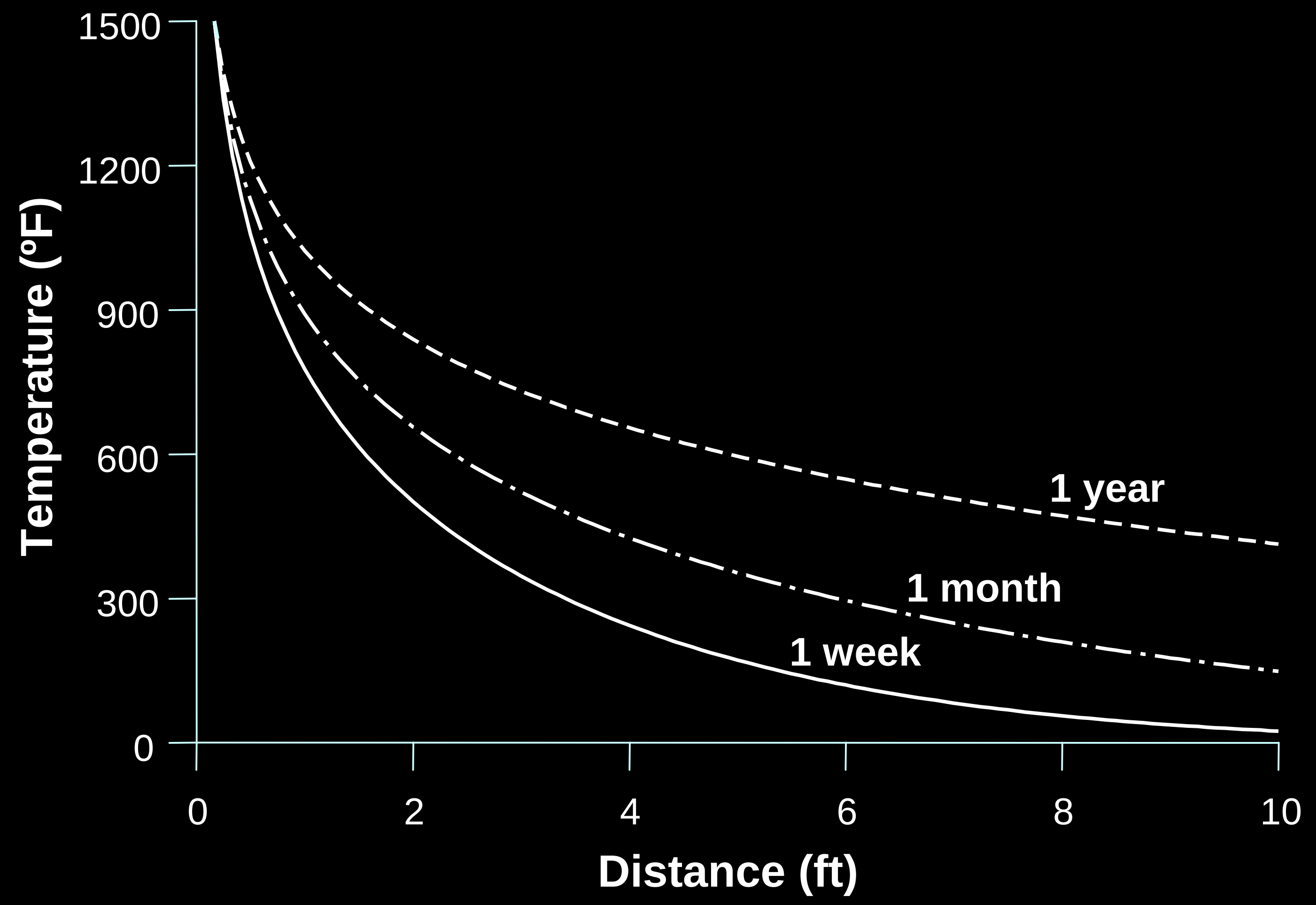
Vapor Pressure of Contaminants

ISTD



Single Well Temperature Profile

ISTD



In Situ Soil Heating Requirements

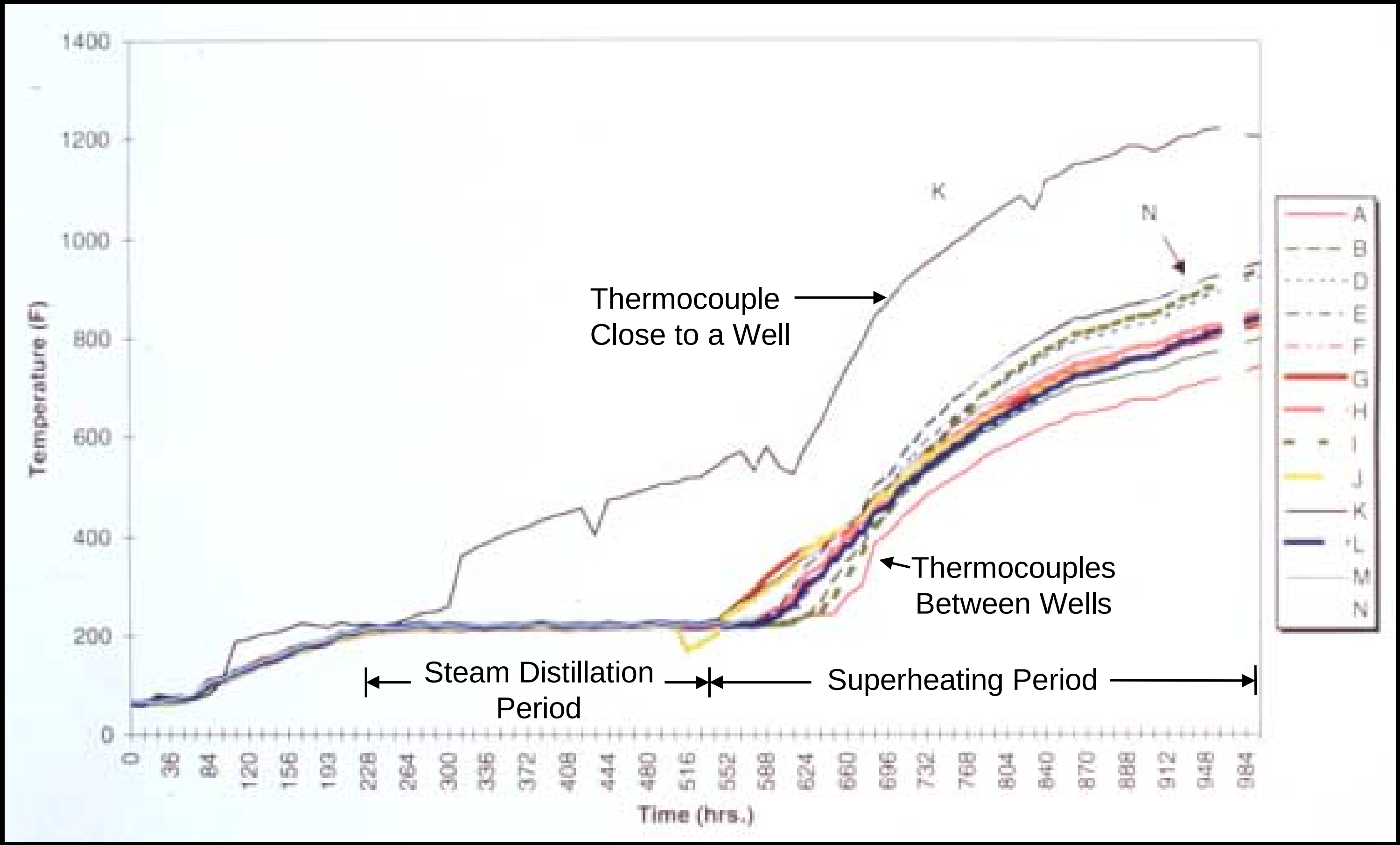
ISTD

- Soil
  - Mineral grains $(1-\Phi)\ \rho_s\ C_s\ \Delta T$
- Water saturation
  - Sensible $\Phi\ S_w\ \rho_w\ C_w\ \Delta T$
  - Latent $\Phi\ S_w\ \rho_w\ h_v$
- Inflow water
- Air
- Power ≈ 10 to 30% of overall cost

Where:
Φ = porosity
ρ = density
C = heat capacity
ΔT = change in temperature
S = saturation
h_v = heat of vaporization
s = solids
w = water

Soil Temperature History at 6 Foot Depth

ISTD: Missouri Electric Works (MEW), Cape Girardeau, MO



Glens Falls Drag Strip (PCBs)

ISTD

Navy: Centerville Beach, CA (PCBs)

ISTD

ISTD Near Residences, Fuel Depot, Eugene, OR

ISTD

Missouri Electric Works: 12-Well Demo

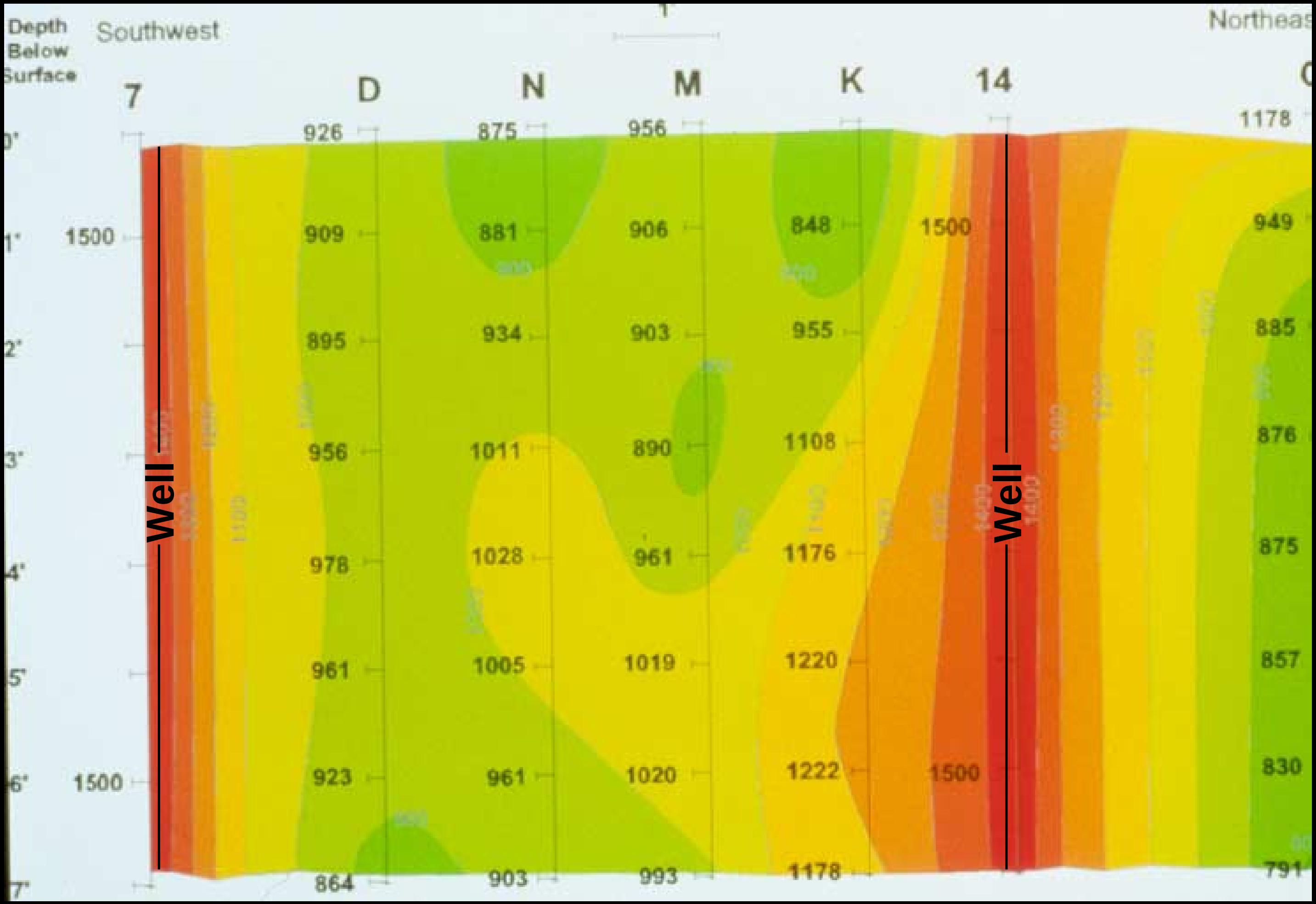
ISTD: MEW

- Superfund site in Cape Girardeau, MO
- PCBs (Aroclor 1260)
- Boiling point: 730 to 780°F
- Depth of contamination: 10 ft
- Soil type: Clay
- Maximum concentration: 20,000 ppm

MEW: Minimum Temperatures (°F)

ISTD

Vertical Profile Through Well Pattern



Results: MEW, Cape Girardeau, MO

ISTD

- PCBs reduced from about 20,000 ppm to non-detect (< 33 ppb) in all 81 soil samples
- Stack testing showed 99.9999998% DRE
- No evidence of contaminant migration
- Dioxins in treated soil below background level (< 6 ppt)

Summary of Thermal Conduction Field Projects

ISTD

Location	Contaminant	Initial Concentration (ppm)	Final Concentration (ppm)
Glens Falls, NY	PCB 1248/1254	5,000	< 0.8
Cape Girardeau, MO	PCB 1260	20,000	< 0.033
Mare Is., CA	PCB 1254/1260	2,200	< 0.033
Portland, IN	PCE	3,500	< 0.5
Portland, IN	TCE	79	< 0.02
Tanapag, Saipan	PCB 1254/1260	10,000	< 1
Eugene, OR	Gasoline/Diesel	3,500/9,300 + free product	N.D. benzene; 250,000 lbs. free product removed
Centerville Beach, CA	PCB 1254	800	< 0.17

(Stegemeier and Vinegar, 2000)

ISTD at Rocky Mountain Arsenal (RMA) Hex Pit

ISTD

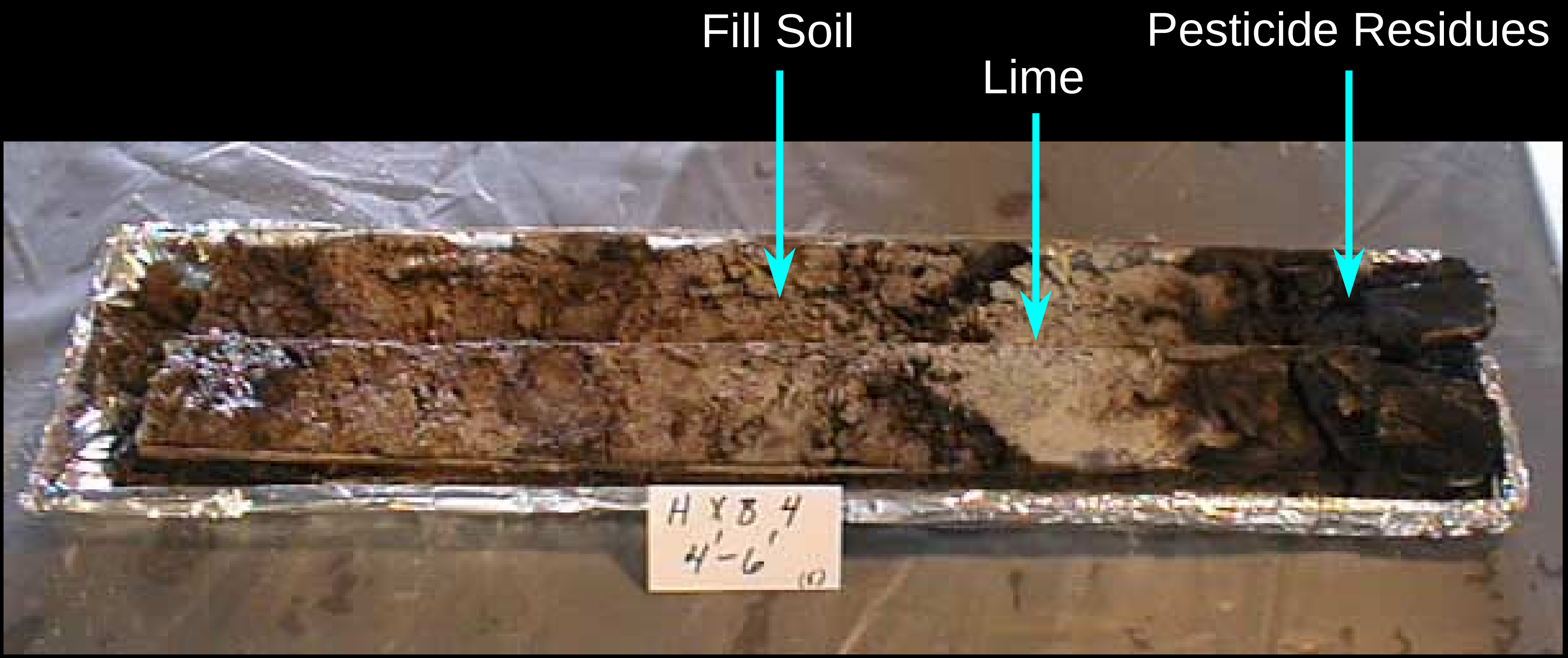
- RMA is DoD's largest Superfund Site
- Hex Pit contains pesticide residues:
  - Hexachlorocyclopentadiene, Aldrin, Chlordane, Dieldrin, Endrin, Isodrin
- U.S. EPA, CDPHE selected ISTD
  - Required In Situ Remedy to Attain > 90% DRE
  - Required Temperatures > 238°C (BP of Hex)
  - Required Robust Technology

Rocky Mountain Arsenal - South Plant

ISTD

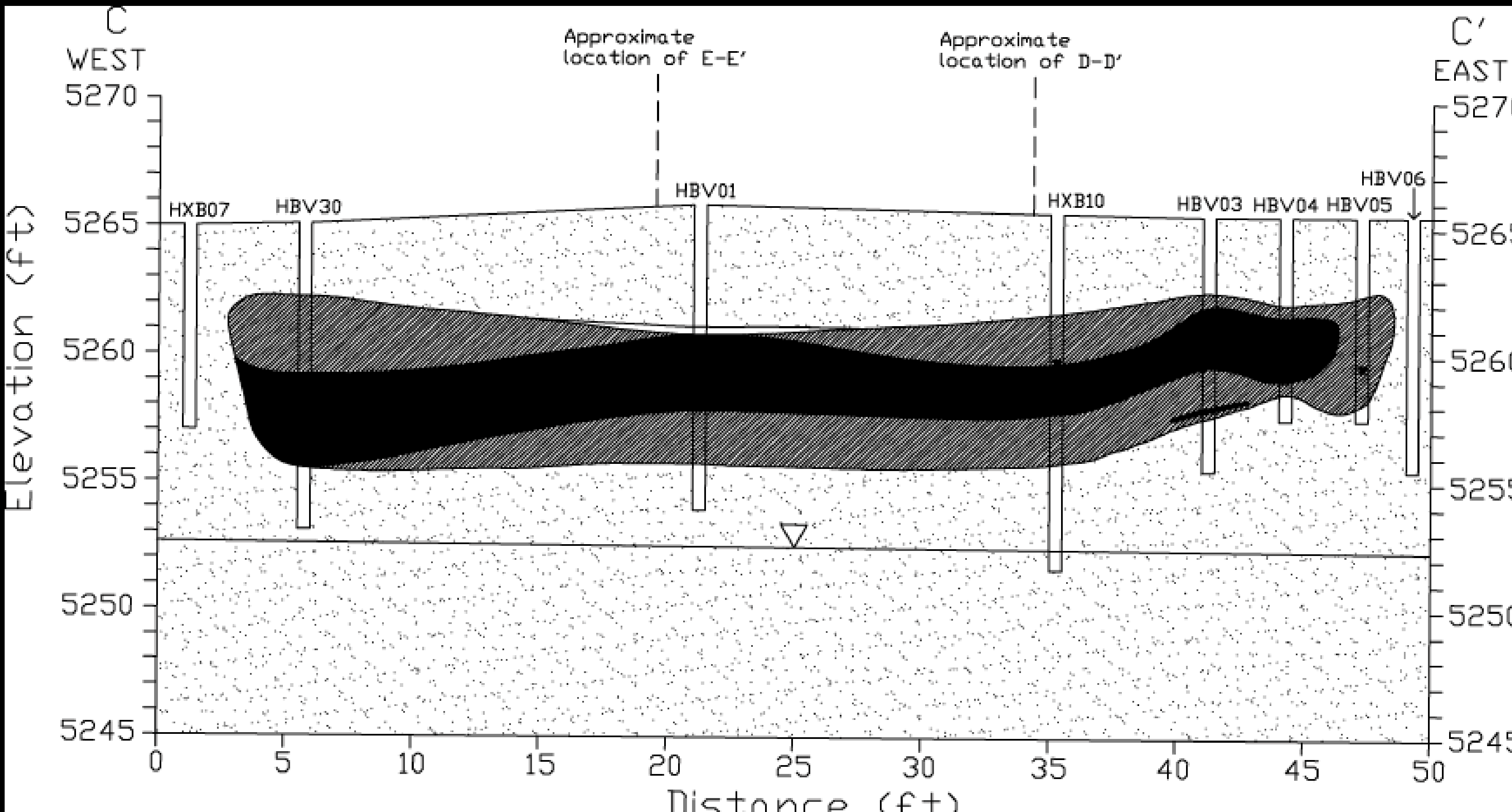
Hex Pit Soil Core (Typical)

ISTD



Hex Pit Cross-Section

ISTD



Dark layer represents waste; cross-hatched area, mixed soil and waste; white layer, lime; while surroundings are visually unimpacted soil.

Materials Subjected to Lab Treatment

ISTD

- Waste Composite: 2 Heating Trials
  - Composite of identifiable waste material from 9-in. Hex Pit borings
  - 21,000 mg/kg hexachlorocyclopentadiene
  - Moisture content = 36.1% (g/g)
  - Dry bulk density = 1.30 g/cm^3
  - Silty sand (USCS); silty clay
  - K_{sat} = 1.6 x 10^{-8} cm/s

Comparison of Pre- and Post-Treatment Results: Waste Composite

ISTD

Contaminant Of Concern		Waste Composite Pre-Treatment		Treated (@ 400° C)	Treated (@ 300° C)	HHE Criteria	PRG	DRE (%)
Hexachlorocyclopentadiene		21,000	LT	2.8	NA	1,100	1,100	99.993
Aldrin		320	LT	3.39	NA	71	0.72	99.470
Endrin	LT	280	LT	5.63	NA	230	NA	NC
Isodrin	LT	200	LT	3.96	NA	52	NA	NC
g Chlordane		2,200	LT	2.5	NA	55	3.7	99.943
a Chlordane		1,400	LT	2.5	NA	55	3.7	99.911
Dieldrin		1,800	LT	2.5	NA	41	0.41	99.931

HHE = Human Health Evaluation
PRG = Preliminary Remediation Goal
DRE = Destruction and Removal Efficiency
LT = less than detection limit
NC = not calculable

Treatability Study Conclusions

ISTD

- Test samples were reduced to below laboratory reporting limits ranging from 2.5 to 5.6 ppm, with DREs > 99.5% for all site COCs
- Permeability of the soil/waste became much greater (10,000 to 100,000-fold) following treatment

Treatability Study Conclusions (Cont.)

ISTD

- ISTD can effectively remove or destroy greater than 95% of the PCDD/F isomers present in the soil/waste materials identified at the Hex Pit Site
- Cumulative efficiency of >99.999% can be expected to produce a 2,3,7,8 TCDD TEQ emission rate of less than 0.002 ng/M^3

Capabilities/Advantages of ISTD

ISTD

- Cleans to very low/non-detect residual levels — achieves 95 to 99+% in situ destruction of contaminants
- Fast — typically < 2 to 3 months operation
- Minimal risk of mobilization due to close spacing of thermal vacuum wells
- Widest heating range of any in situ thermal technology — broad applicability to volatile, semivolatile, and non-volatile hydrocarbons

Advantages of ISTD

ISTD

- Cleans to very low residual levels in situ
- Minimal risk of mobilization
- Complete on-site destruction of contaminants
- Broad applicability to volatile, semivolatile, and non-volatile hydrocarbons
- Process is not hindered by subsurface heterogeneity

Disadvantages/Limitations of ISTD

ISTD

- Not lowest cost for certain sites
  (e.g., relative to excavation or capping)
- Water recharge must be controlled for SVOC sites
- Site must be accessible for well installation

ISTD Price Range

ISTD

- PCBs, Pesticides, Dioxins
  - ~$400/cy for small sites (1,000 cy)
  - ~$200/cy for large sites (100,000 cy)
- BTEX, VOCs, PAHs
  - ~$170/cy for small sites (3,000 cy)
  - ~$60/cy for large sites (100,000 cy)
- Price considerations include site access, air discharge limits, need to control recharge, electricity costs, depth of heating zone/length of heaters, regulatory oversight

Upcoming Full-Scale Projects

ISTD

- Former Southern California Edison Wood Treatment Facility, Alhambra, CA
  - 10,000 cy of PAH contaminated soil to 45 ft
- Manufactured Gas Plant Site, Lake Charles, LA
  - 5,000 cy of PAHs/PCBs contaminated soil to 6 ft

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Summary/Conclusions

Thermal Remediation Technologies

- Promising New Tools to Achieve Environmental Remediation/Facility Restoration Objectives

- "Brave New World": Link Aggressive Source Term Remedies with Cost-Effective Polishing Approaches for Residual Plume
  - e.g., potential to reduce mass flux to allow credible, reasonable timeframe for MNA

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Contact Information

Thermal Remediation Technologies

- **Jim Cummings, TIO/OSWER/U.S. EPA**
  - 703-603-7197
  - **Cummings.james@epa.gov**
- **Eva Davis, ORD/U.S. EPA/Ada, OK**
  - 580-436-8548
  - **Davis.eva@epa.gov**
- **WWW.CLUIN.ORG/THERMAL**
  - Simulcast presentations from EPA in situ thermal seminar – Boston, MA

Contacts (Cont.)

Thermal Remediation Technologies

- **Kent Udell, UC Berkeley**
  - 510-642-2928
  - **Udell@me.berkeley.edu**
- **Roger Aines, LLNL**
  - 925-423-7184
  - **Aines@llnl.gov**
- **Bill Collins, RPM, NAVFAC**
  - 619-556-9901
  - **Collinswe@efdsw.navfac.navymil**

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Technology Vendor Information

Thermal Remediation Technologies

Steam Enhanced Extraction

- Gorm Heron, Steamtech
  - 661-322-6478
- Craig Eaker, SCE/CH2M Hill, Inc
  - 626-302-8531
- Norm Brown, Integrated Water Technologies, Inc
  - 805-966-7757
- Jay Dablow, IT Corp
  - 949-660-7598
- Bernie Gagnon, ENSR Corp
  - 978-635-9500
- Greg Smith, Radian
  - 847-545-7550

Technology Vendor Information (Cont.)

Thermal Remediation Technologies

Electrical Resistive Heating

- Greg Beyke, CES
  - 770-794-1168
- McMillan-McGee Corp
  - 403-686-7186
- Robert Clarke, Geokinetics
  - 510-704-2941

Electrical Conductive Heating

- Ralph Baker, Terratherm
  - 978-343-0300

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References

Thermal Remediation Technologies

- Davis, Eva, How Heat Can Enhance In Situ Soil and Aquifer Remediation: Important Chemical Properties, EPA/540/S-97/502, April 1997
- Davis, Eva, Steam Injection for Soil and Aquifer Remediation, EPA/540/S-97/505, January 1998